SUSTAINABILITY THEORY AND EDUCATIONAL FACILITIES

By

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In 1997 schools in the United States were expending $6 billion annually for their energy needs. The U.S. Department of Energy estimated that at least 25% or $1.5 billion could be saved annually by utilizing the current energy saving technology found in sustainable renewable energy systems. Renewable energy systems were a part of the construct of sustainability. This concept was both theory and practice. It was recognized and well documented that the construct of sustainable renewable energy systems had been applied in business and industry as a cost effective and efficacious option for reducing energy costs. However, due to the scarcity of documented evidence, the use of sustainable renewable energy systems in educational facilities as measured by cost effectiveness and efficacy of similar systems in educational facilities remained unknown. This study endeavored to test the theory and assess the results by combining the perspectives of both the neoclassical theory and the social/ethical theory of sustainability.

The focus of this comparative case study was to test, discern, and document whether the theory of the construct of sustainability, specifically in the area of renewable energy systems, could be utilized in educational facilities as measured by cost effectiveness and efficacy. This study examined two Texas schools that approached supplying their energy needs in the two different ways: one using traditional methods and one incorporating the use of renewable energy. Data were collected to establish a life-cycle cost model for assessing the cost-benefit of sustainable renewable energy systems in place in educational facilities. Efficacy of the systems was established from the perceptions of the participant users of the facilities by use of an oral survey. It was the purpose of this study to test the theory for appropriate utilization of sustainable renewable energy systems in educational facilities in anticipation of providing the needed documentation to support a policy change in the design and construction of educational facilities.

CHAPTER 1
INTRODUCTION

We shape our buildings, but thereafter they shape us.
(Famous quotes and stories of Winston Churchill, 2002)

In 1999 the U.S. Department of Energy forecasted that by the year 2010 it would be necessary to build 6000 plus new schools in order to satisfy the current demand for student stations (U.S. Department of Energy [USDOE], 1999). Since 54 % of all energy consumption in the U.S. was used to operate buildings, the current energy crisis would be exacerbated by new school construction (Florida Department of Education, 1999; Mastaitis, 1999). Energy was not free and was costing U.S. schools $6 billion annually in order to supply their energy needs (Energy Smart Schools, 1997). The U.S. Department of Energy *estimated* that at least 25% or $1.5 billion could be saved annually by utilizing current energy saving technology found in renewable energy systems (Energy Smart Schools, 1997). In 2001 escalation of energy shortages had been demonstrated by both California and Nevada. California had experienced months of rolling blackouts, rising energy costs, and the need for federal assistance to save energy providers from bankruptcy. For the first time in history, Las Vegas, Nevada, had experienced blackouts. The President had proposed oil drilling in environmental lands in order to increase the supply of fossil fuel and to reduce the U.S. dependence on foreign oil imports (U.S. Department of Energy [USDOE], 2001). The precarious political and economical tightrope the U.S. walked with the Organization of Petroleum Exporting Countries (OPEC) had once again been made even more so with the U.S. again at war in

the Middle East. With the ever increasing and continuing demand on finite fossil fuel resources, the energy condition was anticipated to continue to worsen unless remedies were promulgated that would reduce the U.S.'s consumption and dependence on fossil fuels and in the long term, costs (American Association of School Administrators, 1992; Castaldi, 1994; Thomason, 1986). An alternative method to the continued reliance on fossil fuels was to diversify the sources of energy utilized in the United States, focusing on the development of energy from renewable resources, such as solar, geothermal, and wind. Long-term planning on supplying a constant and economical method of producing energy had to take place if future energy supplies were to be available and affordable with the ever-increasing growth of the population. The technology existed for alternative (renewable) energy systems that did not rely on fossil fuel as a resource for energy production (Castaldi, 1994; Kibert, 1996; U.S. Department of Energy [USDOE], 1997).

Renewable energy systems were a part of the construct of sustainability. The concept of sustainable development was both theory and practice (Drummond & Marsden, 1999). It was complex and incorporated the interconnection among three societal elements: economic, environmental, and social/political issues (Kibert, 1999). The focus of this study was to discern and document if the theory of the construct of sustainability, specifically in the area of renewable energy sources, could be utilized in educational facilities.

Thomason (1986) defined educational leadership as having to be both responsive and accountable to the changing needs of education over time. Effectively responding to the dynamic changes that occurred required research for new information for decision makers to create new strategies to keep pace with these changes. This required a departure from traditional thinking. Accountability was the visible outcome of how

effective the response had been applied. Rising energy costs were resulting in a disproportionate drain on school financial resources and had created a need for a reexamination of the traditional energy systems used in educational facilities It had become very critical that school facilities be value engineered for efficiencies in both cost and consumption of energy (American Association of School Administrators, 1992; Castaldi, 1994; Gaul & Kynell, 1980; Thomason, 1986). Legislatures and local school boards had been focused on the initial cost of construction of educational facilities, without examining the long-term impacts of energy efficiency, future energy supplies, high maintenance and operations costs, replacement costs, and environmental impacts. With the service life of a school having been established at 50 years by the Department of Education, the decisions made today will become a cost burden to the local taxpayers for the next 50 years (Florida Department of Education, 1999). It was imperative that construction costs be examined in terms of their life-cycle costs. This was the total or actual cost of the system in place over the service life of the facility. This included initial costs, maintenance costs, operations costs, replacement costs, and in some cases salvage costs. While this life-cycle cost methodology could be used on all aspects of construction, for this study the focus was on the energy and lighting systems used within the facility.

Theory

The construct of sustainable renewable energy systems has been applied in business and industry as a cost effective and efficacious option for reducing energy costs. In relation to the context, rising energy costs for schools predicated on fossil fuels as the resource were resulting in a disproportionate drain on school financial resources (American Association of School Administrators, 1992; Castaldi, 1994; Gaul & Kynell,

1980; Thomason, 1986). An alternative concept was to diversify the sources of energy utilized in schools (Castaldi, 1994; Kibert, 1996; U.S. Department of Energy [USDOE], 1997). In 1997, the United States Department of Energy *estimated* that at least 25% or $1.5 billion could be saved annually by schools utilizing the energy saving technology found in renewable energy systems (Energy Smart Schools, 1997). When tested would the theory stated also hold true for educational facilities?

Statement of the Problem

The use of sustainable renewable energy systems in business and industry is well documented. However, due to the scarcity of documented evidence, the use of renewable energy systems as measured by cost effectiveness (economic) and efficacy (social) of similar systems in educational facilities remains unknown.

Research Questions

1. Are sustainable renewable energy systems, when considered in the context of a life-cycle cost methodology, more cost effective than the traditional energy systems currently utilized in the majority of educational facilities?

2. When in place, is the performance of sustainable renewable energy systems equal to traditional energy systems in delivering a comfortable instructional environment for the occupants?

Sustainable renewable energy systems might provide an option to schools in reducing the financial drain on their budgets due to the rising disproportionate cost of energy without sacrificing the quality of the indoor environment.

This study examined two schools in a Texas city that approached supplying their energy needs in the two different ways: one using traditional methods and one incorporating the use of renewable energy sources. The intention was to develop and ascertain a cost/benefit construct of the two systems In addition, the efficacy issue on how well the systems performed in place was also examined. It was necessary to

examine this efficacy issue in order to assay the overall benefit of sustainable renewable energy systems. Cost was only one factor; equally important was how well the systems functioned on a day-to-day basis. Interruptions in instruction due to an inhospitable environment would certainly negate any cost benefits very quickly.

While the foremost resistance to renewable energy systems had been their relatively high initial cost, when considered in terms of their life-cycle cost would a different picture appear? If the system was durable and operated efficiently, then it might debunk the resistance and illustrate the merits of using sustainable renewable energy systems in educational facilities. This would save school districts much needed scarce funds to fulfill other needs while providing a comfortable indoor climate and might provide useful information to districts who sought options in reducing costs.

Purpose of the Study

It was the purpose of this study to test the theory for appropriate utilization of sustainable renewable energy systems in educational facilities in anticipation of providing the needed documentation to support a policy change in the design and construction of educational facilities. In order to accomplish this, two schools, School A and School B, were examined to ascertain and document differences between the cost and efficacy of the energy systems utilized in the two schools: one with renewable energy sources and the other with nonrenewable energy. This knowledge would be an impetus for direct application and changes in school design. If sustainable renewable energy systems were cost effective and functioned efficaciously in educational facilities, then as a matter of practice state departments of education could move to require them in their current state regulations for the design and construction of educational facilities.

In June of 1999 at a session of the Committee on Health, Education, Labor, and Pensions, Senator Ted Kennedy illustrated the magnitude of the current state of public schools in announcing that nearly one-third of all schools were more than 50 years old and over half of all schools in the U.S. had unsatisfactory environmental conditions (School Facilities, 1999). Environmental conditions were lighting, heating, air conditioning, ventilation, and indoor air quality. The U.S. General Accounting Office in 1995 reported that unsatisfactory environmental conditions were affecting over 45 million students. In addition it reported that America's schools needed $112 billion to upgrade school facilities to an overall good condition rating (U.S. General Accounting Office [USGAO], 1995) The magnitude of need to renovate U.S. schools was clearly evident by these statements. Yet out of the nation's 114,000 schools it appeared less than 1% utilized renewable resource technology to any extent (Energy Smart Schools, 2001). School districts began to examine strategic options for getting the most value out of their scarce capital dollars. This study intended to provide additional knowledge in the utilization of renewable energy systems in order to provide an option for decision makers in deciding how educational facilities could be better designed and constructed for optimum performance at a best value cost over their service life.

Significance of the Study

The primary significance of this study was to add to the body of knowledge in the area of school design and construction. The significance of the knowledge was to help decision makers save money on energy costs that could be used to fulfill other needs of school districts and higher education facilities in the U.S., while improving the environmental conditions of educational facilities (Agron, 2001). The theoretical

foundation of this study was in establishing a cost/benefit construct using an economic model of life cycle costing so decision makers would be able to assess the value of any energy system as to its suitability for their particular needs and objectives.

Information on sustainable renewable energy systems was minimal and scattered with no specific information on a comparative analysis of *in place* systems in educational facilities. If the information did exist, it was not readily available for those who needed to institute changes in the design and construction of educational facilities. It appeared the use of sustainable renewable energy systems, whether mechanical or lighting, was piecemeal, localized, and not widely known or shared (Texas State Energy Conservation Office, 2001). Relatively few were aware of such programs, grants, and initiatives, such as Energy Smart Schools, founded in 1998 by the U.S. Department of Energy as a part of its Rebuild America program. Its major initiative was the Million Solar Roofs Initiative (MSR), which provided grant monies for the installation of solar energy systems. The goal was to have solar energy systems installed on a million roofs across the U.S. by the year 2010 (Energy Smart Schools, 2001). The Solar Electric Power Association located in Washington, DC, a nonprofit organization supported by the U.S. Department of Energy, worked in business partnerships to advance the usage of solar photovoltaic in buildings across the U.S., which included the Schools Going Solar initiative (Solar Electric Power Association [SEPA], 2001). Despite this major deployment of energy efficiency and renewable energy technology, sustainable renewable energy systems were still very much the outliers in the context of energy systems utilized in the nation's schools (Energy Smart Schools, 1997).

Definitions of Terms

Energy management system is an integrated electrical control system used to improve the monitoring, zoning, and control of use of energy in mechanical and electrical systems.

Geothermal energy is the heat in rocks, water, and steam inside the earth that may be tapped to provide both thermal energy and electrical energy.

Life-cycle cost is the comprehensive and actual cost of a material or system in place over its useful or service life. Included is initial cost, maintenance cost, operating cost, replacement cost, and in some instances, salvage cost.

Nonrenewable resources are resources that cannot practically be replenished when used, such as fossil fuels.

Passive solar energy is solar energy collected or controlled by means of utilizing the sun's changing orientation to buildings during the seasonal changes occurring in one calendar year.

Active solar energy is the conversion of solar energy into useable electricity

Peak load is the time period of highest energy demand for a utility company; it is commonly used by utility companies as a basis for differential cost charges.

Renewable energy resource is a resource that is never ending or can be practically regenerated, such as solar, hydroelectric, wind, waves, geothermal, or thermonuclear.

Sustainability means utilizing resources in meeting present needs without compromising the ability of future generations to meet their needs.

Wind energy is the use of wind to produce electricity or for pumping water systems.

Limitations

This study was restricted for the following reasons. This study was a comparative case study. As defined, a case study was concerned with the detailed particularity and complexity of a bounded specific interest in order to obtain a holistic understanding of the particular uniqueness of a case. The data were the vehicle used to facilitate this understanding and to answer the research questions. To this extent, external validity was limited to those schools that were similar to those in the study. And, as such, generalizations would also be limited by the same parameters as those found in the case study and by the inherent limitations of case study methodology.

In order to answer the efficacy question, the researcher conducted an oral survey and asked questions to a selected group of respondents. The questions were limited to those posed by the researcher and, therefore, restricted the answers of the respondents. The responses were limited to those perceptions of the selected group in this study. This group's knowledge of sustainable renewable energy systems and traditional energy systems and how they functioned would also have inherent limitations in answering the questions. The number of respondents also created limitations; however, the number of respondents was inherently limited by the job positions that the respondents held in the school district, such as the district administrators involved with the district's facilities and the school administrators (i.e., the principals of the two schools). The number of classroom teachers were selected by their respective principals and were limited in number so as not to disrupt the instructional process in the two schools. While the number of respondents was limited, their intimate involvement with the subject schools and the day-to-day functional environment of schools could produce accurate perceptions

as to efficacy of the energy systems despite the limited number. The subject schools were chosen for their similarities in order to limit extraneous variables and to focus on the differences in the energy systems alone. Lighting systems were included because they had a direct impact on the overall energy efficiency of a facility.

Summary

To respond to the increasing demands for energy and the rising cost of that energy, the development of strategic options in resolving this issue for educational facilities was required. Balancing the disproportionate drain on financial budgets of school districts in supplying energy needs was imperative in a time of scarce funds. If this could be accomplished by testing whether sustainable renewable energy systems were appropriate for utilization in educational facilities and also reduce the demand for more fossil fuel generation, then a win-win outcome could be realized for both consumers and the environment.

A large portion of the nation's energy consumption was utilized by its buildings. Educational facilities were part of this genre and all operated during peak-load periods at the highest cost rates. Business and industry had already begun to utilize renewable energy systems in buildings; it was time to examine the traditional way of supplying energy to educational facilities in an effort to bridle an escalating problem. If consideration in utilizing new technology and a new approach was not taken, then schools could find themselves facing electrical blackouts or financial cataclysm.

New reports, initiatives, research, and grants had revealed that new technologies were readily available in alleviating the escalating energy consumption and costs experienced by schools, although documentation as to the cost effectiveness and efficacy

of renewable energy systems was unavailable. The change of focus from initial cost to life-cycle cost became an important consideration in light of the current state of condition of the majority of schools. The actual or true cost of a building, material, or system over its entire life span was a major principle in the construct of sustainability and had become an important factor in the design and construction of schools, especially since it had not previously been considered. While the initial cost of sustainable renewable energy systems was still currently slightly higher than that of traditional energy systems, using life-cycle cost analysis might illustrate that, in the long term, they were the best value.

In partnership with the cost effectiveness of sustainable renewable energy systems was the qualitative issue of the efficacy of those systems. Cost was just one factor; how the system operated on a day to day basis was equally important. System malfunctions that required extended down periods for repair would affect the comfort level of the instructional spaces and hinder the teaching process. The aggravation of disruptions in the instructional process would soon negate the benefit of any cost savings or positive contribution to the environment.

Policy changes have always been difficult in education. The inherent complexity and bureaucracy of the educational system have made arduous the introduction of major changes. It was the purpose of this study to test the theory for appropriate utilization of sustainable renewable energy systems in educational facilities in anticipation of providing the needed documentation to support a policy change in the design and construction of educational facilities. Change from traditional thinking was in itself the one process that met with the most resistance (Maser, 1997). It was embraced only when it was absolutely inescapable to do anything to the contrary. And it was this change from traditional

thinking that was needed in order to investigate new ways, ideas, and technologies in order to resolve the current energy challenges. This concept of a change in thinking was best depicted by Albert Einstein when he said, " we cannot solve the problems that we have created with the same thinking that created them" (Trzyna & Osborn, 1995, p. 37).

Outline of Study

Chapter 2 contains a review of the literature relevant to this study. Methodology used in the study is detailed in Chapter 3. Results of the study are presented in Chapter 4, and Chapter 5 contains conclusions, implications, and recommendations.

CHAPTER 2
REVIEW OF RELATED LITERATURE

In 1962, Rachel Carson's controversial book Silent Spring was published. While the focus of the book was on the effects of pesticide usage, Carson unwittingly launched the concept of environmentalism into everyday life. Previously, the idea was called conservation and was generally limited to discussions about national parks (Carson, 1962). Soon after publication of Carson's book, however, Congress began holding hearings on the environment. Senator Abraham Ribicoff introduced her at the hearings as the woman who started the whole thing. The environmental movement began and changed the philosophy of how mankind related to nature from one of domination to one of being in balance with nature, solidifying the indisputable interconnection and cause/effect relationship between humans and their environment (Carson, 1962).

The environmental movement continued to expand and grow since Carson, encompassing many areas of everyday life, such as air pollution, water and ground contamination, water conservation, material toxicology, wildlife preservation, land preservation, waste management, resource utilization and conservation, energy conservation, and indoor air quality. Forcing a big picture, or holistic, perspective was one of the domineering characteristics of sustainability, examining every aspect of a situation over the long term and in the process cutting across multiple professions and disciplines (Trzyna & Osborn, 1995).

Although the general population may have been more familiar with the term green building, a broader, more comprehensive term associated with the environmental design and construction of buildings was sustainability, which came from the root word sustain, as in to maintain or keep in existence. The Brundtland Report defined sustainability as meeting present needs without compromising the ability of future generations to meet their needs (Kibert, 1999). This intergenerational concept was not new and found its origins in the early 18th century, but the present day sustainable movement found its origins in the 1970s, having evolved out of the concept of "ecodevelopment" (Trzyna & Osborn, 1995).

Sustainability was both a theory and a practice (Drummond & Marsden, 1999). While some aspects of sustainability moved from being completely theoretical to applied and practiced, many aspects still remained conceptual challenges that required understanding, defining, and testing. Lacking was evidence of both the real potential and constraints in achieving sustainability goals and principles (Drummond & Marsden, 1999).

Siebert, in his writings, saw the sustainability theory, not as a single stand-alone theory but interconnected to the theories of economics, allocation, and optimization (1995). From an economic perspective, he considered the environment as a scarce resource where its goods and services were no longer in ample supply; its decreased supply would have a direct effect on economics and allocation. In terms of optimization, the total quantity demanded of any commodity could not exceed the output. In this respect, the theory of sustainability was related to the concept of optimal growth and sought to find a balance between economic growth and degradation of the environment (Siebert, 1995).

Drummond and Marsden approached the theory of sustainability more from a social/ethical perspective rather than Siebert's economic perspective. They saw sustainability as a means of promoting harmony between humans (society) and the environment through the social/ethical consideration of nondegradation of the environment's resources, stressing the intergenerational role and responsibilities of society. This social/ethical consideration also included the theory of regulation. Social regulation was inherent in institutions, structural framework, norms and values in all capitalistic development. Understanding the influence that these regulations imposed on development in general, in essence would direct the nature of development to one of either sustainable or unsustainable. However, they recognized the merits of other perspectives, whether economic, social, or purely environmental, and concluded that sustainability was a multidimensional concept and fundamentally integrative. (Drummond & Marsden, 1999).

While the meaning of sustainability was clear and consistently used as meaning a continuum through time, the implications of sustainability within a given context remained ambiguous. What should and should not be sustained and in what context still remained to be defined (Maser, 1997). There were still gaps that existed between what was possible within the context of sustainable development and sustainability concepts tested under real conditions. Sustainability, to a great extent, was still defined in the abstract and needed to be tested in terms of empirical and analytical evidence. Sustainability was, in many instances, simply rhetoric, ambiguous, and open to many interpretations, unless it could be objectively defined by quantifiable evidence so it could be used to inform policy changes (Drummond & Marsden, 1999).

One approach to defining sustainability was to use the system approach in managing the complexity and enormity of the concept of sustainability. Energy and money would be recognized as a system and evaluated separately and collectively as part of the whole of sustainability (Drummond & Marsden, 1999). The energy systems that have been designed in the past have interacted with the environment and changed it and are continuing to become further distanced from environmental balance. A system must be evaluated as to whether it is sustainable, always cognizant of the importance that sustainability was an integrated approach; if one process was left out of the evaluation, then an outcome other than the one intended may result (Maser, 1997).

The energy issue in sustainability was multidimensional and prohibited simple optimization rules for making decisions. Conflicts between political, economical, and environmental goals hindered the ability to use a traditional single-dimensional approach. A multidimensional analysis was important and necessary in order to evaluate the sustainability of energy issues with efficiency as a key factor (Nijkamp, 1983). One strategy proposed was that of a modified neoclassical theory; imputing market values to environmental costs and benefits (Redclift, 1999). This neoclassical theory was the predominate theory for assessing, understanding, and achievement of sustainability in the United Kingdom and the United States. To a great extent, it contributed to the economic analyses of environmental problems (Jacobs, 1999). The inherent problem with this strategy was the focus on money alone as the objective without consideration for the true value to humanity. According to Redclift, what was needed in sustainability was more of a balance and the opportunity to prioritize sustainability goals over materials, energy, and environmental values when needed (1999). This study endeavored to test the theory and

assess the results by combining the perspectives of both the neo-classical theory and the social/ethical theory of sustainability.

Sustainability in the design and construction of buildings was comprised of many parts: the design and layout of communities, buildings, and infrastructure, building materials and methods, renewable energy sources, energy utilization and efficiency, water conservation and management, indoor air quality, alternative wastewater treatment, landscaping and pest management, waste management, deconstruction of buildings, and transportation (Kibert, 1996). All of these parts came together to make up the whole of environmental or sustainable design and construction. This study concerned itself with one of these parts in one type of building, alternative or sustainable renewable energy sources in educational facilities. The long stable service life of an educational facility lent itself nicely to the *prospect* of a large sustained cost reduction over many years in energy utilization, which has the *potential* to offer a huge cost benefit to both school administrators and taxpayers (American Association of School Administrators, 1977; Castaldi, 1994; Florida Department of Education, 1999). While alternative energy sources as a means of heating, cooling, ventilating, and lighting a building played a predominate role in energy efficiency and cost reduction, it was also beneficial to give equal consideration in the design and construction process to all of the other parts of sustainable construction that determined whether or not a building was sustainable (i.e., this study was only one facet of the larger context). The design and construction of educational facilities were predicated on a holistic approach in order to obtain maximum results in achieving comprehensive sustainability; but if that was not feasible, then any single effort was certainly better than no effort at all (American Association of School Administrators, 1977; Kibert,1996; Sustainable Systems, 1997).

Traditional School Design

Historically, the school building was not distinct in its fabrication or utilization, often serving a twofold purpose for education and community gatherings. It was not until the later part of the 1800s that schools were designed specifically as schools and the most common design was the "egg-crate" design. This was a collection of boxes arranged next to each other which formed individual classrooms and influenced school design for the next century (Ortiz, 1994). School buildings, in general, were divided into two major categories, pre-World War II (WWII) and post-WWII (American Association of School Administrators, 1992). The pre-WWII buildings were palaces with ornate architecture to disguise them as schools in both the visual and functional sense. Many had artistic elements of enormous entrances, high ceilings, and massive corridors making them both impractical in wasted, nonuseable space and large energy consumers (Castaldi, 1994). Thirty-one percent of U.S. schools were built prior to WWII with more than half of all schools today built during the 1950s and 1960s in order to accommodate the mass of "baby boomers" that had reached school age following WWII (American Association of School Administrators, 1992). These post-WWII schools were often built cheaply and quickly in order to satisfy a crisis in the shortage of student stations. This crisis management response to provide a mass of student stations cheaply and quickly was the driving force in how and why many decisions involving school design and construction were made (Savory, 1999). The post-WWII schools also fell victim to the architectural style of the time, often described as "bringing the outside in." Buildings were designed and constructed using large window walls with expanses of glass to allow students a panoramic view of the outdoors. These large expanses of glass also permitted a large amount of heat and sunlight to transfer into the buildings. The 1960s also brought the

finger and campus designs which allowed large energy losses through the multiple number of outside walls (Castaldi, 1994). Castaldi details that there had been little regard as to the high maintenance and operations costs that these schools would incur and all three designs required enormous energy utilization to heat and cool the buildings, but energy was plentiful and relatively inexpensive at the time. There was no consideration given to long-term planning of the maintenance and operations of these schools or the impact a changing energy supply might have on them (Castaldi, 1994). Lean budgets due to lack of adequate funding since the 1970s created the phenomenon called deferred maintenance. The quick and cheap schools of post-WWII suffered deteriorating materials and systems that districts could not afford to repair or replace in lean budgets; consequently, items needing repair became deferred year after year until over half of the school buildings in the U.S. were considered in deplorable condition (Education Writers Association, 1989). It was estimated in 1991 that it would take over $100 billion to satisfy the deferred maintenance needs of U.S. schools (American Association of School Administrators, 1992). Both pre- and post-WWII schools suffered from energy inefficiency. The scarce funding exacerbated by the energy shortage of the 1970s, which increased the cost of energy, made these schools very burdensome on school district operational funds. They required a disproportionate part of the budget to pay their very expensive energy bills, and with no way to pass on the increased costs, they had to meet the higher prices by cutting programs and services (American Association of School Administrators, 1992; Castaldi, 1994; Gaul & Kynell, 1980; Thomason, 1986). Many other schools simply reached the end of their useful service life due to age and obsolescence. The average age of school buildings in the U.S. was 42 years old (National Center for Education Statistics, 1999). There was no consideration as to the

changing spatial needs that might occur in the future with changing pedagogies, and these schools had inflexible designs that necessitated very expansive, difficult, and expensive renovations for any space alterations (Castaldi, 1994).

A leading designer in educational facilities, Henry Sanoff, emphasized the importance of the design of facilities and the impact they have on the overall well-being of both the institution and its occupants. He pointed out that many educational facilities not only had been designed poorly but were outdated due to age. In the past, decisions had focused more on building plans rather than educational plans, the majority of decisions having been made without user participation. Designs for educational facilities had been formulated almost in a vacuum by "the professionals" with little or no participation on the part of the educators or occupants (Sanoff, 1994). This was also reflected by J. W. Getzels, who noted that while the learning process had changed dramatically, the role of the physical environment had changed very little in order to keep pace with the changes in the learning process (Getzels, 1975). Basil Castaldi affirmed this idea that, overall, school buildings had been incidental to the learning process (Castaldi, 1994). School facilities not only had been falling apart, disproportionately costing districts to maintain them, but also had not functioned with modern learning processes. While the discipline of educational facility planning was found in localized areas, for the most part there were few school boards or campus facility planners that were cognizant that good educational facility design was a collaborative process among educators, designers, and builders (King & Marans, 1979; Sanoff, 1994). Designing, constructing, maintaining, and financing had been largely a local matter with little or no knowledge of innovative or cost reducing methods. Decision makers were more often than not at the mercy of the expertise of the local architect employed by the district with school administrators having insufficient access to quality facility and energy efficiency

information (American Association of School Administrators, 1992). Consistent budget reductions, which prevented school districts from affording the necessary resources and expertise to do long range and innovative planning, inhibited the ability to stop the vicious circle. In many cases, districts were at risk of repeating the same mistakes made in the 1950s and 1960s (Education Writers Association, 1989).

The traditional method primarily focused on the number of student stations, the minimum number of square feet required to provide those student stations, and the required square footage for administration, teacher, and ancillary functions in order to provide the minimum requirements to satisfy the current need (Castaldi, 1994; Ortiz, 1994). Focused on satisfying the current needs without regard for future needs, schools fell victim to whatever current architectural style was in vogue regardless of the maintenance and operations costs they incurred. The quick construction focused exclusively on the initial cost of the construction, not what the long term costs would be to keep the building materials and systems in good condition over the life of the school. And there certainly was no flexibility to accommodate any changes that would have occurred in the future, whether it was costs or pedagogies (American Association of School Administrators, 1992; Castaldi, 1994; Getzels, 1975; Sanoff, 1994).

Sustainable School Design

In their book School Sanitation and Decoration, Burrage and Bailey demanded that "If the children are compelled by law to attend school, the authorities should spare no pains to make their environment the best" (Burrage & Bailey, 1899, p. 1).

Trzyna and Osborn (1995) illustrated that the lack of use of sustainable principles in design and construction was not due to a lack of knowledge or research, but essentially was a problem of power or, more precisely, the lack of power to change traditional

thinking and actions. While pedagogies have experienced substantial changes in developing individuals' learning abilities, little had been done in changing the environments in which this learning takes place (Gayeski, 1995). Called ecological or environmental psychology, this discipline examined the interconnection of human behavior and the physical environment, which included light, sound, temperature, and layout (Proshansky, 1975). It has been shown to be difficult to concentrate in a room that was an uncomfortable temperature or noisy and poorly lit; these environmental issues had been directly correlated to performance and productivity (Gayeski, 1995). Estimates revealed that student performance could be improved from 5.5% to 11% by the improvement of the physical environment and that student attitudes had been directly affected by the condition of their learning environment (Lackney, 1994). These issues and more were all considered in sustainable school design.

Sustainability was a holistic approach that considered the long-term implications and impacts of the design and construction of buildings. It was a complex one that incorporated the interconnection among three major societal elements: economic, ecological, and social issues. Economics was concerned with the initial cost, maintenance, operations, and replacement of materials and/or systems of a building. Ecological issues involved all the resources that were required in order to facilitate construction, operation, and building consumption needs and the interaction the building had on the natural environment around it. Social issues concerned the building's interaction in the community and the health and well being of those who occupied and used it (Kibert, 1999). In contrast to the quick fix of the 1950s and 1960s to produce schools without regard to the long-term consequences, sustainable schools had endeavored to solve the current condition problem without creating additional problems

in the future life of the school. The past and current methodology in the design and construction industry was a cradle-to-grave mentality of wastefulness and inefficiency (Kibert, 1999). This mentality had carried over into school construction as well. Schools had been built fast and with as cheap an initial cost as possible without regard to what costs would be required to maintain and operate the school over its lifetime. The sustainable school had been designed and constructed with careful thought given to

- building orientation on the site in relation to the sun through all four seasons in order to maximize passive solar principles.
- utilizing nontoxic or low-toxic materials to minimize allergic or sensitivity reactions to the occupants and maximize indoor air quality.
- using materials that minimize the impact on ecosystems and finite resources.
- building materials and building systems that are durable, requiring little replacement, and maximizing energy efficiency.
- using daylight for energy efficiency and occupant comfort.
- using renewable energy systems for energy and economic efficiency.
- using natural, indigenous landscaping to minimize water and pesticide usage minimizing the negative impact the school building(s) will have on the natural habitats and ecosystems.
- minimizing the single car as a means of transportation by utilizing access to public transportation, bicycle and walkway access.
- reducing waste by utilizing reuse and recycling whenever possible during construction and building operations.
- using water conservation methods for irrigation and toilet facilities.
- utilizing a set routine system of maintenance in order to keep materials and systems in optimum condition and uses non toxic cleaning agents.
- using a life-cycle cost analysis to determine the actual cost of the school over its lifetime (Ayres, 1998; Kibert, 1996, 1999; Malin, 1999; Maser, 1997; Miller, 1995; Savory, 1999; SHW Concepts, 1998; USDOE, 1997).

While the design process of a sustainable building followed the same step-by-step logical analysis as required by the design of a traditional building, the concepts were different (USDOE, 1997). The requirement of a change of thinking from the traditional methodology seemed to be the most difficult hurdle to overcome and the one process that met with the most resistance (Maser, 1997). Information had been available to professional designers, builders, and educators on sustainable development to those who sought it; however, more needed to be done to disseminate this information on a much larger scale and, in many cases, to quantify by documentation that the theoretical concepts were in fact true and achievable (Maser, 1997).

While information on the health effects of chemical toxicity on both the environment and humans began with Rachel Carson's book, its leading-edge concepts were more often than not met with skepticism or outright disbelief (Carson, 1962). This skepticism has not abated in sustainability, especially in the area of renewable energy systems. The lack of documentation of renewable energy systems under real conditions perpetuated this skepticism to current times. Carson's book was insufficient in changing the traditional viewpoint on design and construction. Information from the mid-1990s began to focus not just on health/environment interaction but also on the monetary aspects of those issues, moving from the pure social/ethical theory perspective to the neo-classical theory perspective. Approaching the information from a business and monetary view, Paul Hawken illustrated how businesses could develop an environmental consciousness in doing business and continue to make profits, in an effort to capture interest by appealing to the economic sector. By calculating the costs associated with the total ecology of the earth's water, atmosphere, climate, and soil at $33 trillion a year,

businesses that did not account for those costs would face losses not only on resources but on capital, demonstrating that environmental capital is both necessary and profitable (Hawken, 1994; Lovins, Lovins, & Hawken, 2000; Reinhardt, 2000). Analyzing good environmental practices from a business perspective had been shown to be financially beneficial and profitable, not just for the consumers but also for the manufacturers. Using practices that were good for the environment was no longer just a social responsibility but also a financial responsibility (Reinhardt, 2000).

Life-Cycle Cost Analysis

Life-cycle cost (LCC) was a comprehensive method of analyzing the total cost of an item over its entire life span. LCC included the first, or initial, cost and all other costs associated with maintenance, operations, replacement, and disposal over the entire useful life or over a specified period (Florida Department of Education, 1999). The life-cycle cost was the true, or actual, cost that an item would sustain over its service life.

Traditionally, public entities, including school districts, had been focused on the initial costs of construction because of the perceived savings of taxpayer dollars. In reality, lowering the initial costs by cutting quality had resulted in higher operating, maintenance, and replacement costs over the service life of the building. Less expensive buildings initially often had resulted in more expensive buildings over their life (Florida Department of Education, 1999; Kowle, 1979). Judgements based on only the initial cost result rather than life-cycle cost resulted in a large portion of wastage over the life of the building (Lovins, Lovins, & Hawken, 2000). Utilizing life-cycle costing was a key energy saving measure that resulted in actual, not perceived, cost savings (Kowle, 1979).

Present Worth Method for Comparison

Net Present Value (NPV) was the value of a benefit or cost in the present time. The time value of money was an assumed concept in financial analysis where money today was worth more than money in the future. It reduced cash flows over a span of time to a single number down to a present time or base year (Collier & Glagola, 1998; U.S. Department of Defense [USDOD], 2000). It was this single number that was used for comparing alternatives based upon their equivalent present worth. The major factors in NPV analysis were the time, inflation rate, and the discount rate (interest) in order to compare the value of a dollar at present time to a time(s) in the future (USDOD, 2000; Kibert, 1996). Inflation and interest rates were factors that must be selected based on an educated assumption. Since no one could be absolutely sure what the inflation or interest rates would be in the future, rates were chosen based on historical data. Inflation rates for the last decade ranged from a high of 5.4% to a low of 1.6%. For the year 2001, the estimated inflation rate based on the Consumer's Price Index (CPI) was 3.2 per cent (U.S. Bureau of Labor Statistics, 2002). For the purpose of this study, the inflation rate was assumed to be 3.0%, which is an average of the inflation rates of the last decade based upon the U.S. Bureau of Labor Statistics. Because there were a variety of ways in which school construction could be funded from Federal and State funding to corporate-sponsored funding to tax credit bonds, which provide for interest-free financing, interest rates may or may not be a factor dependent on the type of funding (Financing School Facilities, 1999; White House, Office of the Press Secretary, 2000). For this reason the discount rate was assumed to be 0%. The formula is

$$NPW(t) + P\frac{\left\{(1+i)^t\right\}}{\left\{(1+d)^t\right\}}$$

Where P is the initial cost of the system, i is the inflation rate, d is the discount rate, and t is the time. The service life of the facility was set at 50 years, using the State of Florida Department of Education guideline (Florida Department of Education, 1999). The service life must be the same for all alternatives in order for the comparison to be valid (Collier & Glagola, 1998).

Traditional Energy Systems

Traditional energy systems were those mechanical and electrical systems that provided the heating, air conditioning, ventilation, and lighting for a building. These systems provided the internal environment's climate and comfort in terms of temperature, air quality, and lighting, and research had shown that all of these factors had a direct bearing on student academic achievement, performance, and attention spans (Burrage & Bailey, 1899; Gayeski, 1995; Lackney, 1994). Traditional systems were reliant upon the fossil fuels of coal, crude oil, or natural gas as a means of supplying the energy to operate them. The fossil fuel was typically converted into electricity, the most common and convenient form of energy (Lechner, 1991). In energy conversion, the First Law of Thermodynamics and the Second Law of Thermodynamics were important to note. The First Law of Thermodynamics stated that energy could be neither created nor destroyed, only changed in form; and the Second Law stated there was always a loss of energy when energy was converted from one form into another. The losses for conversion to electricity were typically in the form of waste heat and accounted for 70% (i.e., only 30% of the original fossil fuel became useable electricity) (Lechner, 1991). Despite these facts, the majority of school facilities were all electric, due to the aggressive promotion from electric companies during the 1950s and 1960s when the

majority of existing schools were built and the majority of electricity was generated by fossil fuels (Castaldi, 1994).

Although there were many types of mechanical systems that handled heating, ventilation, and air-conditioning (HVAC) concerns, the type utilized was based upon several design criteria. The orientation of the school building on the site in relation to the sun, the number of buildings that comprised the school, the number and type of rooms, the material and construction of the building(s) envelop, the size and amount of glass windows, the climatic conditions of the geographical area, the initial cost, the maintenance and operations costs, and the expertise of the maintenance staff (Castaldi, 1994; Haines & Wilson, 1998; Kowalski, 1989). Reviewed here were some of the more common HVAC units typically utilized in school buildings, some combining heating and cooling operations into a single unit and others separating heating and cooling operations.

The simplest unit was the package unit, whether installed through an outside wall or on the rooftop over the particular classroom. These units were self-contained HVAC systems and were considered single-zone (i.e., they function for a single room). Each room required its own unit, including hallways. These units provided both heating and cooling operations, but control of outside air was not usually included in the typical unit; however, there were units with humidity controls available. These units, while having a low initial cost, were high energy users, due to the low efficiency of the unit and the lack of central control of operation. The maintenance was simple, but their life span was relatively short at an average of 10 years, making replacements frequent and costly, especially for roof top units that deteriorated at a higher rate due to exposure to the weather and sun. Since a unit was required for every space, they required a great deal of

building space, were aesthetically an eyesore, and noisy to room occupants (Colen, 1990; Florida Department of Education, 1999; Haines & Wilson, 1998).

The direct expansion (DX) split system was similar to the package unit in operation, the difference being that the air handler and the condensing unit were separate from each other. This allowed for the air handler to be placed within the room, above the ceiling, or in a closet. The condensing unit was located outside and, if not located near classroom windows, would reduce the noise nuisance. Split systems came in single zone or multi zone, reducing the need for so many individual units. The heating and cooling functions were included in the same unit, with heating provided by electrical heat strips. The initial cost for this system ranged from low to moderate, with maintenance similar to the package unit. These systems were also similarly high energy users with a slightly longer life span averaging 15 years (Colen, 1990; Florida Department of Education, 1999; Haines & Wilson, 1998).

The heat pump was a common system used in regions with warm climates. Combining both heating and cooling functions, they could easily serve multiple zones more efficiently than the split systems. This was, in part, due to the fact that the refrigerant line had the ability to allow the flow to switch direction permitting the flow of heat to move from the inside to the outside for the cooling operation; and to move from the outside to the inside for heating operations provided the outside temperature was above 40 degree F. In order to heat below 40 degrees, auxiliary heat strips were required, diminishing energy efficiency. There were many varieties of heat pumps with the primary difference being the heat source and sink, which could be air, water, or earth. The air-to-air heat pumps could produce two to three time more heat more efficiently than the heat strips. The initial cost of the heat pumps was low to moderate, depending

on the size and number of zones; however, it was considered a moderate energy user unlike the package and DX split system units. The maintenance was relatively easy with an average knowledge of mechanical systems to repair them. Depending on the unit, life expectancy could be anticipated at 15 to 20 years. They typically were not used in colder climates where outside temperatures were commonly below 40 degrees F because they did not heat efficiency at lower temperatures and their energy cost became high (Colen, 1990; Florida Department of Education, 1999; Haines & Wilson, 1998).

Central HVAC systems came in a variety of combinations and could easily be used in either warm or cold climates. The central chiller could be air cooled or water cooled with wide configurations possible with respect to pumps, piping, ducts, and controls. A system could contain a single chiller or dual chillers for redundancy as a back-up system. If one chiller failed or required routine maintenance, the second chiller would operate and maintain occupant comfort. Heating was provided by a separate boiler that shared the same piping or by heat strips; however, heats strips were high energy users and not an efficient way to provide large scale heating. Piping could be in the form of a 2-pipe or 4-pipe system. In the 2-pipe system, one pipe functioned to supply chilled water or hot water, and the other served as the return back to the central plant for rechilling or reheating. The convenience of the 4-pipe system allowed for the cooling and heating functions to have their own exclusive 2 pipe system. This provided both convenience and efficacy in those climates when temperatures might have been cold in the morning and warm in the afternoon. When transition took place from heating to chilling, or vice versa, there was minimal lag time to convert from one to the other (i.e., pipes did not have to warm up or cool off). This instantaneous heating and cooling provided for greater occupant comfort. The central system typically used variable air

volume (VAV) boxes to maintain air temperatures within rooms. The boxes adjusted automatically via the controls to maintain the proper air amount in order to maintain the desired temperature. Controls were typically direct digital controls (DDC) that allowed for central operation and efficiency via a computer. The central system had great flexibility allowing additions and renovations to be easily added or modified. Larger systems cost less in initial costs than their DX split system counterparts and were, on average, lower to operate, especially centrifugal chillers. In geographical areas where electrical costs were high and priced by peak and non-peak rate structures, ice storage systems could have been added to a central system. These systems ran the condensing units at night during nonpeak rates in order to make ice, which was stored in underground tanks. During peak hours when rates were the highest cost, energy efficient variable speed circulating pumps circulated the water through the ice, chilling it to the desired temperature. Some utility companies offered rebates to users who installed ice storage systems relieving energy demand during peak hours. Maintenance was relatively convenient since the chillers, pumps, water treatment, and controls were centrally located; however, these systems required highly trained personnel. The redundancy of a back up chiller also provided for convenience because maintenance could be done during normal working hours—one unit could continue to operate while the other was down for repairs. A central system that incorporated a separate air handler for outside air (required for ventilation) or an attached heat exchanger that dried the air, could better control humidity levels in those geographical areas where humidity was a problem. The ASHRAE standard 62-1989 required 15 cubic feet per minute of fresh air for every occupant of a school building. Controlling the humidity of entering fresh air decreased growth in molds and mildews and provided better control of indoor air quality. Schools

with humidity problems reported indoor air quality problems 4 to 1 over schools that did not (Florida Department of Education, 1999). The initial cost on central systems was medium to high, depending on the size of the chillers and the required amount of ancillary equipment, such as piping, pumps, controls, and building area required to house the equipment. Operations and maintenance costs were typically in the medium range compared to other systems, and energy costs ranged from low to high depending on the system chosen. The cooling towers were noisy and were not located near classrooms. The average life of a central system was 25-plus years requiring only one replacement in a 50-year service life (Colen, 1990; Florida Department of Education, 1999; Haines & Wilson, 1998). Mechanical heating and cooling systems were the single largest consumer of energy in a school building and were designed by a mechanical engineer for optimum energy savings and performance (Florida Department of Education, 1999).

Lighting in schools was critically important in order for students to have a comfortable visual environment. It accounted for the second highest usage of energy in a school building, consuming up to 50% of all electrical energy in the U.S. (Florida Department of Education, 1999; Harroun, 1984). Lighting was measured using three types of measurements. The measurement used in quantifying the intensity of lighting was the foot-candle, defined as the intensity of light striking a surface at a distance of one foot from a standard candle (Castaldi, 1994). The amount or rate of light that was emitted from a bulb was measured in lumens. In comparing equivalent 100-watt lamps, an incandescent bulb would emit 1,740 lumens, a flourescent bulb 7,800 lumens, and a high pressure sodium vapor bulb 9,500 lumens. This difference in the amount of lumens per watt was called efficacy (Lechner, 1991). The brightness or the reflectance of light off a surface was measured in footlamberts and technically called luminance. Identical

100-watt incandescent bulbs would reflect light differently depending on the color and texture of a surface, and brightness played an important role in the clarity of vision in the human eye. Too little or too much reflection distorted clarity. Additionally, contrast was important, the difference between a focused detail and its immediate background. Visual clarity could be heightened by maximizing the contrast between an object and its surrounding background. The greater the contrast, the less illumination (footcandles) were necessary to achieve visual clarity. If contrast was not considered in illumination design, than glare could occur. A 100-watt bulb would cause more glare when the background was a black ceiling than if the ceiling was white (Castaldi, 1994; Lechner, 1991). Traditional lighting systems in schools were artificial lighting, either in the form of fluorescent or incandescent lighting The required footcandles for the typical classroom was 30 to 40, with hallways only requiring 10 to 15 and speciality rooms, such as drafting, art and libraries, requiring up to 50 to 70 (Castaldi, 1994). The majority of artificial lighting in schools was flourescent, because flourescent fixtures produced 50% more lumens than incandescent per kilowatt hour of energy (Castaldi, 1994). While there had been objections to the harshness of the cold, bluish light they emitted, developments in artificial lighting created warmer light tones with the creation of full-spectrum fluorescent bulbs that mimiced natural lighting (Rath & Ittleson, 1981; Sustainable Systems, 1997). Fluorescent lighting made it easy to illuminate large areas with diffused lighting, but they did not function well for beam or task lighting (Lechner, 1991). While fluorescent bulbs had a long life (average life of 15,000 hours), they were still large consumers of energy; and in areas where energy costs were high, they provided a significant source of energy consumption (Lechner, 1991).

Renewable Energy Systems

In 1899, Burrage and Bailey wrote in their book on school design about the importance of proper heating, cooling, ventilation, and lighting systems for the well-being and performance of students. In 1994, Castaldi was writing, in essence, about the same thing but within the context of modern equipment. Within the span of 100 years, the importance of the subject was never questioned; but how best to accomplish that task in modern times had come under scrutiny and argument. The point of the argument was how best to supply the required energy to run the mechanical and lighting systems. There was a growing cognizance that fossil fuels were a finite resource and extremely costly in many areas of the country, especially since the oil crisis of the 1970s (Kibert, 1994; Strong, 1999). Considering that oil did not become the primary fuel in the U.S. until 1950 and in the World until the mid-1960s, it was curious that within 10 to 20 years a relatively inexpensive source of energy reached crisis levels of both supply and cost (Golob & Brus, 1993). The U.S., which had been energy self sufficient, was now reliant on imported oil from the Middle East and fluctuating market prices. The Gulf War in 1990 brought about another price spike, and it was anticipated that there would be more in the future (Golob & Brus, 1993). The idea of trade among nations, once considered a good thing, was being reconsidered in certain areas due to the conscious raising of the 1973 oil embargo and the U.S. vulnerability to the fluctuations of the Middle East oil suppliers (Wilbanks, 1983).

Large scale production and usage of fossil fuels, primarily coal, did not occur until the middle to late 1880s. Prior to that, people relied upon renewable energy sources, especially in the forms of solar, wind, animal fat or plant oils, and natural lighting (Strong, 1999). Environmental advocates urged a return to the concept of using

renewable energy sources to produce energy, instead of fossil fuels. This would provide independence from OPEC price fixing, less vulnerability to wars and political coups, provide long-term cost effectiveness, and reduce significantly the air pollutant emissions that were generated from production and oil utilization, primarily carbon dioxide (Bossel, 1998; Golob & Brus, 1993; Johansson, Kelly, Ready, & Williams, 1993; Kibert, 1999; Strong, 1999; Williams, 1998). While there were many different types of renewable energy systems, such as gasified biomass, hydrogen as fuel, and hydroelectric power, this study concerned itself with three main types that were applicable for use in school facilities—solar, wind, and geothermal.

Solar energy was responsible for life on earth. While the sun emitted 2 billion units of energy into space, the earth received approximately only 1 unit out of 2 billion; and there was evidence that this rate of energy had been fairly constant for the last 5 billion years (Greeley, Ouellette, & Cheremisinoff, 1981). The U.S. receives more energy from the sun in 40 minutes than it does from the fossil fuel it burns in one year (De Laquil, Kearney, Geyer, & Diver, 1993). Solar energy was abundant, constant, nonpolluting, inexhaustible, renewable, and free. It could be used for both heating and cooling (Castaldi, 1994). Solar energy was utilized in two different forms—passive solar and active solar, also known as solar photovoltaics (Bobenhausen, 1994).

Passive solar design had been used to some extent by all civilizations, but it was the Romans who developed passive solar designs in their buildings. These designs were commonly used and recorded in Roman writings (Lechner, 1991). The objective of passive solar design was to maximize the attributes of the sun and to integrate them into the design of a building in a synergetic approach and minimize the use of any mechanical devices. Building orientation in relation to the sun, walls, roofs, windows, building

materials, natural daylighting, natural ventilation, shading, and landscaping were all components of passive solar design (Lechner, 1991; Sustainable Systems, 1997). Passive solar designs had a distinct advantage of only slightly increased initial costs, lower maintenance, higher reliability, and created a more pleasant indoor environment (Golob & Brus, 1993; Lechner, 1991; Sustainable Systems, 1997). Passive solar worked on the simple principle of collecting the solar heat by use of south facing windows or skylights and stored the heat in a thermal mass, typically a thick concrete wall, and was radiated into the room in the evening when temperatures became cooler (Lechner, 1991). Buildings with a large area of windows were oriented facing south, which provided heating in the winter and shading in the summer (Castaldi, 1994; Lechner, 1991). Passive solar design was a highly integrated holistic approach to building design and included all building systems, not only one. While there were passive solar design principles, there was no typical design that would work on every building—passive design was site specific. It was incorporated into building design even with traditional energy systems in enhancing energy efficiency (Sustainable Systems, 1997).

Active solar energy or solar photovoltaics, as it was technically called, was the conversion of solar energy into useable electricity (Building-integrated Photovoltaics, 2001). There were two basic types of photovoltaic systems, the stand alone and the utility interactive. While both systems used photovoltaic cells (panels) for collection, the stand alone used a battery storage system to store the electricity generated with a diesel fuel generator as a back-up. The integrated system was connected to a traditional electrical utility grid system as a means of back-up. Any additional electricity not needed was not stored but fed into the grid system, or more accurately it was sold to the utility company (Brown & DeKay, 2001; Building-integrated Photovoltaics, 2001; Sustainable

Systems, 1997). Photovoltaics could be designed to supply all of a buildings' energy needs or partial needs, such as supplementing heavy loads during the summer months or heating domestic hot water supplies (Brown & DeKay, 2001). Photovoltaic cells were made of several types of semiconductor materials, the primary material was silicon, the most common material on earth, and could be thick or thin. Thick cells were more efficient in converting solar energy to electricity than thin, but thin require less material and were very lightweight (Lechner, 1991; Sustainable Systems, 1997). Both converted sunlight into direct current (DC) electricity and required an inverter in the U.S. to convert the DC current to AC power. Photovoltaic systems required designing by professionals, like traditional systems, in order to ensure they would supply the amount of needed power and provide the appropriate storage capacities and /or needed back-up systems. The batteries used for storage typically last 20 years or more and require very little maintenance (Lechner, 1991). Also crucial was the layout and orientation of the cells. When oriented properly to true south (Northern Hemisphere), they would collect more sun, increasing efficiency, and in order to provide an increase in overall annual production of electricity cells, were set at a tilt matching the site's latitude (Brown & DeKay, 2001; Sustainable Systems, 1997). Also available for limited space applications were transparent cells that could be used for window glazing (Lechner, 1991). While the reluctance to use solar photovoltaics was quite understandably due to its high initial cost (cells cost over $1,000 per peak watt of power in 1970), they had dropped in price considerably due to new technologies. They cost just under $5 per peak watt of power in 1997, and in 2001 were selling at below $3 per peak watt (Building-integrated Photovoltaics, 2000; Sustainable Systems, 1997). Considering the cost of electricity per peak watt in many areas of the country and for suppling power to rural areas, the cost of

photovoltaic energy was becoming increasingly cost effective. Cost effective defined by the U. S. Energy Policy and Conservation Act, as amended by the Energy Policy Act of 1992, as providing a payback period of less than 10 years. In most cases if a rural facility was located more than a quarter to half a mile from a power supply, the savings of not having to bring power to the site would offset the cost of a photovoltaic system (Brown & DeKay, 2001; Building-integrated Photovoltaics, 2001; Lechner, 1991; Sustainable Systems, 1997; White House, 1994).

Domestic hot water could also be heated by photovoltaics. Either from waste heat off a main system or by a small stand alone system, the term being solar thermal system (Building-integrated Photovoltaics, 2001). It was the most common use of solar energy in the U.S. and worldwide (Chauliaguet, Baratsabal, & Batellier, 1977). By 1991 there were over 1.25 million solar hot water systems in the U.S. and over 5 million in Japan and 900,000 in Israel. Both countries, like the U.S., were heavily dependent on imported fossil fuel. Israel required them on any buildings under eight stories (Golob & Brus, 1993). While solar thermal systems were discovered by the Greeks in the third century B.C., the first practical systems were designed in Europe and the United States in the late 1800s (International Energy Agency, 1987). A solar thermal system for hot water could be either a direct system, where water was circulated directly through the cell panels; or as an indirect system where the water was heated by use of a heat exchanger. Recirculating water with antifreeze circulated from the solar collector cells through the heat exchanger, heating the water in the tank. Circulation could be achieved either by natural means of gravity, called thermosiphon, or by mechanical or forced means using a pump (Chauliaguet et al., 1977). A recirculating system would insure that hot water was readily available even in large buildings (Bobenhausen, 1994; Sustainable Systems,

1997). The long life span of a school lent itself to the long-term cost efficiency of energy from the sun. Using solar to heat hot water was very cost effective and economical and could have been used in all schools. Many states and the Federal government were paying part of the costs through grants (Castaldi, 1994).

The future of solar energy continued to look positive with decreasing prices for photovoltaic systems, new technology, and increasing fossil fuel costs. As of 1997, there were over 500 megawatts of solar photovoltaic energy produced worldwide (Sustainable Systems, 1997).

Wind energy systems were not commonly utilized as a renewable energy source, even though wind theoretically was an inexhaustible as the sun (American Association of School Administrators, 1997). The first wind systems were used in Europe in the 12th century (Lechner, 1991). Wind systems could produce electricity more cheaply than fossil fuel systems or nuclear systems with costs as low as $0.039 per kilowatt hour, making them competitive to both systems (Sustainable Systems, 1997). While wind systems could not be used everywhere because the minimum requirement was an average of 13 mph wind speed for 90% of the year for electricity generation, there were many areas in the country that would be suitable. In order to know whether or not an area was suitable for wind energy, a wind rose was constructed that gave detailed information on wind speed, direction, and frequency on a month to month schedule for an entire year. This information was provided by data that was generated from the Airport Climatological Summary Report produced by the U.S. Department of Commerce (Brown & DeKay, 2001). Wind systems could also be used for pumping water systems instead of generating electricity making them very flexible systems (Strong, 1999; Sustainable Systems, 1997). The initial cost for wind systems was also less than solar with

projections stating that in the next 10 to 15 years wind systems would become the cheapest energy of any source (Sustainable Systems, 1997).

The available energy from wind was calculated as the cube of the wind speed. If the wind speed doubled then the energy output would be eight times greater (Brown & Dekay, 2001; Lechner, 1991; Sustainable Systems, 1997). They used the same storage systems as solar photovoltaics, typically a battery system (Lechner, 1991). Wind machines could be placed on tall towers, the average was 30 feet high, or placed on the roofs of buildings (Lechner, 1991). The negative aspect of wind systems was the perceived visual effects of the equipment and occasional collisions with birds. Research was being done to eliminate those negative aspects (Sustainable Systems, 1997). The Energy Policy Act of 1992 provided a tax credit of 1.5 cents per kWh generated by wind energy systems for the first 10years of operation for any systems installed between December 1993 and July 1999, with the hope of stimulating the development and use of wind energy (Sustainable Systems, 1991).

Geothermal energy systems, which accessed and utilized the earth's natural thermal properties for heating, had been used for thousands of years (Strong, 1999). In fact, the thermal energy stored in the immediate six miles of the Earth's crust contained 50,000 times the energy than all of the oil and gas supplies in the world and was the largest known energy source on earth, containing 35 billion times the world's current total annual energy consumption (USDOE, 1997; Palmerini, 1993). It had been used to generate electricity since the early 1900s (Palmerini, 1993; U.S. Environmental Protection Agency [USEPA], 1978). There were two basic types of geothermal energy that were used commercially, hydrothermal reservoirs and earth energy (Strong, 1999). In hydrothermal reservoirs, subterranean hot water was piped directly to heat buildings

and provide hot water needs, hot water being defined as having a temperature of 302 degrees F. or more (USDOE, 1997; USEPA, 1978). In harnessing earth energy, a piping system in conjunction with a geothermal heat pump utilized the earths' constant internal temperature, which occurred between 5 and 50 feet below grade. Although the depth varied from area to area, geothermal energy was found worldwide (Palmerini, 1993; USDOE, 1997). Geothermal heat pumps would heat /cool buildings and heat hot water reducing electricity consumption by 30% to 60% and achieved a 95% customer satisfaction rating, the highest of any energy producer (USDOE, 1997). The U. S. Department of Environmental Protection Agency defined geothermal heat pumps as one of the most efficient and least polluting energy systems currently available, providing the lowest maintenance and operations costs and lowest life-cycle costs (systems typically lasted 30 years or more) and utilized nationwide (USDOE, 1997). Direct access to hydrothermal reservoirs resources were found primarily in the western states, Alaska and Hawaii (USDOE, 1997). According to the U.S. Department of Energy, half of the U.S. trade deficit could have been reduced if the U.S. would have relied upon available domestic renewable energy sources instead of importing foreign oil (USDOE, 1997). For electricity production, geothermal power plants were located in California, Nevada, Utah, and Hawaii and were responsible for producing 2700 megawatts of electricity, equivalent to 58 million barrels of oil, while at the same time producing only 1/1000 to 1/2000 of the amount of pollution caused by fossil fuel power plants, and costing 80% less than fossil fuel (USDOE, 1997).

Daylighting

Daylighting was the term used to coin natural lighting. It used and conducted natural light into interior building spaces from the exterior environment and partially or

totally replaced the need for artificial lighting (Florida Department of Education, 1999). In daylighting, light was distributed into the interior of the building by means of windows, skylights, atria, roof monitors, clerestories, sawtooths, or courtyards (Florida Department of Education, 1999; Lechner, 1991; Nicklas & Bailey, 2001a). Up until the mid-20th century and the advent of inexpensive fluorescent lighting, all buildings used natural lighting as a means of illumination (Lechner, 1991). Cheap electricity and better designed fluorescent light fixtures allowed designers flexibility to design without attention to window size and location (Lechner, 1991). The energy crisis of the 1970s brought attention to energy conservation and, along with mechanical systems, reconsideration of how a building was lighted became a concern (Castaldi, 1994; Lechner, 1991). Buildings, especially schools, could have reduced energy costs up to 64%, reduced need and expenses on cooling equipment and energy consumption, reduced expenses on maintenance and operation, produced superior full-spectrum lighting, improved health and performance, and decreased absenteeism by using daylighting (Nicklas & Bailey, 2001b). The nature of daylight and its affect on the human biological need in relating to the natural rhythms of a day had produced increased research into its stimulation, productivity, and sense of well-being on humans (Florida Department of Education, 1999; Lechner, 1991; Nicklas & Bailey, 2001b).

A daylighting design that worked under conditions of both overcast skies and clear, sunlit skies worked under any other sky condition (Lechner, 1991). Even the light emitted by an overcast sky was still 10 to 50 times greater than the needed light for any visual task (Lechner, 1991). In daylighting design, lightwells were constructed as part of the building structure and sunlight traveled through translucent fabric baffles or was reflected off of room surfaces, such as ceilings, in order to eliminate any direct radiation

into the space. The orientation of the lightwells, or monitors as they were also called, was also important. The south orientation was usually best because it received direct sunlight the majority of the day and throughout the year. The north orientation was the second best due to the fact that while the sunlight was constant it did not have as much quantity of light as the south; however, the quality of the light was high. In hot climates, such as the sunbelt areas, the north orientation might have been the preferable one due to the reduced solar heat gain (Lechner, 1991). The depth of light penetration was controlled by window height. This allowed the sunlight to be distributed equally without creating excessive light levels and by reducing the potential heat load to that below what would be generated by artificial lights (Lechner, 1991). If properly designed, the heat load from daylighting would produce only 2 btu of heat for every 1 btu of light in comparison to the 3 btu of heat for every 1 btu of light from fluorescent lights and 12 btu of heat generated by incandescent lights (Lechner, 1991). Spaces were designed to have over 70 footcandles of light for at least two-thirds of the day and, in most cases, the cost of daylighting components added minimal additional cost, less than 1% of construction costs, especially since the mechanical equipment and electrical system requirements were able to be reduced by half with the overall per square foot construction costs of day-lit schools being comparable to non-day-lit schools (Nicklas & Bailey, 2001a). In Nicklas and Bailey's examination of daylit versus non-daylit schools in North Carolina from July 1993 to July 1994, they found a reduction in energy costs of $.25 to $.32 per square foot, depending on utility prices and climatic conditions. This equated to a reduction of between 22% to 64% of energy costs between daylit and non-daylit schools and a payback of less than 3 years (Nicklas & Bailey, 2001a).

In relationship to the health and well-being of students, a study conducted on the effects of light on elementary students concluded that, in using full-spectrum daylight, students had less absenteeism by 3.2 to 3.8 days per school year, libraries experienced less noise levels, students' mood levels were elevated, and due to the additional Vitamin D from sunlight, students showed a nine times greater reduction in tooth decay and grew on average 2.1 cm more over a 2-year period than students in artificial lighting (Hathaway, Hargreaves, Thompson, & Novitsky, 1995). In addition, Nicklas and Bailey did an analysis of student performance in daylit schools in North Carolina and found that students in daylit schools showed an increase in standardized test scores of 5% to 14% over students in nondaylit schools. The percentage level was dependent on the length of time that students had been attending a daylit school. In addition, one daylit elementary school that showed an increase of 7% in scores was destroyed by fire necessitating the relocation of students into portable classrooms, their scores subsequently decreased by 17% the following year (Nicklas & Bailey, 2001b). It was interesting to note that Burrage and Bailey's book published in 1899 also noted that in schools with natural daylighting, student's had cheerful moods and less absenteeism. The authors noted that medical doctors felt that there could never be too much natural light in schools because of its health benefits to students; and on days when it was dark and required the use of artificial lighting, instead of subjecting students to eye strain and other maladies that occurred with artificial lighting, it would be better to dismiss school (Burrage & Bailey, 1899).

While it was necessary that a full artificial lighting system be included in daylit schools as a supplementary backup system, a well-designed daylit school should necessitate artificial light usage no more than a third of the day. This provided a

substantial reduction in energy usage. What must be guarded against was the habit of personnel from automatically turning on the artificial lights without consciously thinking, since the increase in illumination of artificial lights and daylighting was not perceived as a negative to the occupants, thus nullifying the energy savings. In order to prevent this, the addition of automatic controls was necessary. Photocells that prevented artificial lights from being turned on when light levels were adequate and automatically turned off when rooms were vacant should be utilized in order to maximize the energy savings benefits of daylighting (Lechner, 1991).

Summary

It was almost assured that Rachel Carson in 1962 had no idea that her book would be responsible for launching the environmental movement that has been experienced in current times. Her conscious-raising research was the catalyst to a reexamination of the way people lived and did business in relationship to their environment. While the focus of the original environmental research was one of a social/ethical perspective and was focused on the health effects of pollution on humans and nature, the 1990s saw the rise of the monetary, or neoclassical, theory and the monetary benefits of good environmental practices. This broadening of the environmental picture resulted in changing a concentration from that of initial cost to that of life-cycle cost in determining the actual cost of an item or activity. The perspective of developing a long-term strategy, not just a short one, began to enter mainstream thinking.

It was a natural progression that the theory of sustainability would enter the discipline of the design and construction of school facilities. After examining the historical background of when, where, how, and why schools were built, it was evident that the reason the majority of today's schools were built, and how they were built, was a

short-term solution to the baby boom crisis following WWII. Built fast and cheap in order to satisfy the large influx of new students, the focus was not on the potential future problems that cheap materials and energy consuming designs would cause for future school administrations. It was no wonder that over half of the schools today were considered in deplorable condition, expensive to maintain, and draining school budgets.

New schools continued to be built in the same traditional way as the old, partly because that was all people knew and also because budget constraints prevented them from researching and instituting new ways to build. They continued to repeat the same mistakes as made in the past. As the concept of sustainability continued to grow and expand into many disciplines and professions, it finally entered into the design and construction of schools via environmental psychology. This discipline examined the relationship between humans and the effect their physical environment had on their well being and performance. Research began to examine this relationship in terms of students and the physical environment of their schools. The holistic, interconnecting precepts of the theory of sustainability were pushed by the few innovative practitioners into the design and construction of a limited number of schools. Changing the thinking from the traditional to the sustainable was the hardest obstacle to overcome.

Since school districts began to suffer under repetitive budget reductions, with no money to do the required maintenance on their facilities and with high energy bills consuming such a disproportionate amount of their funds, they faced cuts in their services and programs for students in an effort to balance their budgets. Schools administrators needed to investigate ways to keep their facilities from depleting their resources for their students. Some administrators became interested in energy efficient designs and equipment and the long-term effects of maintenance and operations of their

schools and their budgets. They focused on the key element of energy consumption, which had become the fastest rising cost in their budgets.

While there were many traditional mechanical and lighting systems that were efficient and suitable for schools, such as the heat pump for warmer climates or the central chiller/boiler systems, technology had brought into focus the financial *feasability* and environmental benefits of investigating mechanical and lighting systems from sustainable renewable energy sources. What was lacking was documented evidence that these systems would be cost effective and efficacious to use in schools. Since oil did not become the primary source of fuel in the U.S. until 1950 and within a span of 20 years reached crisis levels of both supply and cost, examining sources that provided self sufficiency and low cost was now of interest to school administrators and districts. Solar, wind, and geothermal were all types of renewable energy sources that might be possible to incorporate into school design with a reasonable initial cost and a very low life-cycle cost. Schools would no longer be captive of fluctuations in energy costs and supplies. Renewable energy was free and abundant. A very few innovative schools began to incorporate renewable energy, either in whole or part, into their schools with the help of government grants and tax credits and in cooperation with many utility companies. Tapping into the renewable energy sources of the past, they began, with the advantages of new technology, to attempt to supply their energy needs with a life-long efficiency by using solar, wind, and geothermal energy systems. In keeping with the sustainable renewable energy sources, they also began to use natural daylighting instead of artificial lighting to illuminate schools. Also used in the past, the use of daylighting returned with enhanced benefits due to new technologies in design and construction, and some schools

realized the positive attributes of student well being and performance and energy efficiency that were the assets of daylighting.

While the use of sustainable renewable energy sources and natural daylighting was still very sporadic and piecemeal, more and more school districts began to want to investigate these alternatives in an effort to cut their energy consumption and costs in the face of continued budget reductions.

CHAPTER 3
METHODOLOGY

A case study can employ parts of many research methods in order to gain an understanding of a specific bounded instance, emphasizing focus on the object and not on the process. The case becomes an integrated system within itself (Stake, 1995). The case study methodology was employed in this study to test the theory that the construct of sustainable renewable energy systems that had been applied in business and industry as a cost-effective and efficacious option for reducing energy costs would be appropriate for educational facilities. This case study borrowed techniques from ethnographic, case, and holistic qualitative methods and was designed quantitatively as a retrospective cohort, an observational method of reviewing data over a period of past time, in order to create a unique system to study this particular case. While generalization in the purest scientific sense does not occur in the context of case study, generalization does occur in a limited sense to situations that are like or similar to the one in this case study. Validity in the case study was increased by using the triangulation protocol of three levels of users to minimize the inherent bias in interpretation by a single group. It assured that in analyzing the qualitative data that there was a logical interpretation of that data and its meaning (Stake, 1995).

Design of the Case Study

This study was a comparative case study, comparing two Texas schools: School A that utilized sustainable renewable energy systems and School B that did not utilize

renewable energy systems. Data were collected in order to fully understand the particularities and complexities of this circumstance, to answer the research questions, and test the theory. The two schools selected were chosen for the ability to control extraneous variables. Both schools were elementary schools, designed by the same architectural firm with the same approximate square footage. They shared the same occupancy rate of 680 K-5 students and were located within 2 miles of each other, eliminating any differences due to climatic conditions. Both schools were oriented in a North/South exposure on their sites. This case was organized around the issue of the cost effectiveness and efficacy of using sustainable renewable energy systems in school facilities. In comparing two schools (one which utilized renewable energy systems, and one that did not), the uniqueness of this issue was observed in place and, in a holistic manner, by exercising the attributes of both quantitative and qualitative questions. As stated, this case study was organized around the issue of sustainable renewable energy systems in school facilities. The two main research questions asked were

1. Are sustainable renewable energy systems, when considered in the context of a life-cycle cost methodology, more cost effective than traditional energy systems currently utilized in the majority of educational facilities?

2. When in place, is the performance of sustainable renewable energy systems equal to traditional energy systems in delivering a comfortable instructional environment for the occupants?

While cost was an important outcome, a better understanding came from including and examining the qualitative question of efficacy. There was an inherent bias in interpretation of the data; however, in order to gain a more complete picture, it was included and bias minimized by using the triangulation protocol. Triangulation was accomplished by interviewing three levels of users of the facilities in examining efficacy; district administrators, school administrators, and classroom teachers. By analyzing the

responses to the same set of questions, from the three different levels a more comprehensive interpretation was generated.

Data were collected to establish a life-cycle cost model and create a tool that could be used to assess specifically the cost-benefit of renewable and traditional energy systems *in place* in educational facilities, in order to examine and determine cost effectiveness. Life-cycle costing was a key measure in sustainability (renewable energy systems) resulting in actual, not perceived cost savings. All cost data was collected from the school district's and contractor's archives. Initial cost came from the respective contractor's schedule of values and final contract price including any change orders that occurred during construction. Operations and maintenance costs came from the district's records of utility and maintenance costs that occurred during the 12-month period beginning in July 2000 through June 2001, which was the first year of occupancy for both schools. Interviews with the Director of Maintenance and manufacturers provided data on routine maintenance (material and labor hours). The labor costs were calculated using the district's wage cost including labor burden. Replacement was determined from related research, manufacturer, and industry recommendations. Calculations were based upon an inflation rate of 3%, a discount rate of 0%, and extrapolated to a 50-year service life based on standard net present value formula. This study assumed salvage costs to be zero.

Demographics of District, Schools, and Geographical Environment

This case study took place in a North Central Texas suburb of a major metropolitan city, a community founded in 1848 and the county seat. Its history boasts of Frank and Jesse James as frequent visitors in years past. It appeared to be a thriving and busy community complete with the assortment of chain restaurants, stores, and mall.

From conversations with the participants and the census data, this community had been experiencing a rapid increase in growth. It looked similar to any Florida city of equal size. The 2000 census showed a population of 54,369 people within the city and 491,675 in the county. The county population had increased by 86.2% since 1990. The city population was estimated to increase to 58,986 by 2001 showing the area had been in a growth period for the last decade, primarily due to the increase in telecommunications jobs available in the major city only 30 miles away. The 2000 census data showed the median age of its residents at 30.6 years with 36.4% of the population in the range of 25 to 44 years of age and 76.8% of the population were families with children under the age of 18. The total number of housing units in the city was 19,462, with a 93.4% occupancy. The 12-month average for unemployment for the area was 3.8%, below the national average. The land area of the county was 848 square miles with 579.8 persons per square mile. The business community was a mix of retail, commercial service, and light industry. The largest single employer was a manufacturer of defense electronic systems, the second largest employer was the local community colleges, and the third was the combined government employees of the city and county. The population was primarily single family with an average of 3.0 persons per household. The median household income was $75,280 with only 4.7% of the population below the national poverty level. The population was composed of 81.4% White, 4.8% African American, 6.9% Asian, 10.3% Hispanic,.5% American Indian, 50.6% male, and 49.4% female. Of the current population, 50% held college degrees. The area was served by a municipal airport, national bus carrier, all major truck lines, and rail service. Regional and International air travel was located 30 miles in the major metropolitan city. The total construction dollars spent for 2001 were $149,380,740 for single family, $28,193,420 for

multi-family, and $33,063,916 for nonresidential. In the last three years over 4,756 housing permits had been issued for single family housing, 1766 for multi-family, and 317 for nonresidential. The majority of the businesses were new, having been built in the last 5 years. There were two local electric power providers, and neither distinguished between peak and nonpeak times in establishing their rate structure. One had a reserve of 15.1% at peak demand and the other 26.9% reserve.

The Texas elementary and secondary schools were divided into independent school districts that operated autonomously within their localities. This independent school district had a total of 21 schools, composed of 13 elementary, 3 middle, 2 high, 1 head start school, 1 students-at-risk school, and 1 school for students recovering from addiction. The city also had 3 private schools. In 2000 there were 5,719 elementary students, 2,363 middle school students, 2,172 high school students, 297 in private school, and 250 enrolled in the head start school. The average student/teacher ratio for the elementary schools was 22:1. The district had experienced and anticipated a continued growth rate of students at 11% per year. The graduation rate was 96.9% with the average SAT score of 1,063. The district's current operating budget was $98,500,000. There were 3 community colleges in the local area and 4 universities within 50 miles. There was a small 270-bed hospital, 54 churches, 19 parks, 1 area lake, and a variety of recreational activities. One central library serviced the city.

The State of Texas was considered to be located in the general area known as the Sunbelt. The local land area was generally flat and located at 670' above sea level. The annual average temperature was 65.7° F, the monthly average high was 96° F., the average low temperature was 33° F, showing a large temperature differential between summer and winter months. Record lows had been recorded at -7° F and record highs at

118° F. There were an average of 234 sunny days annually and an average wind speed of 9-13 miles per hour, predominately from the south. The time of the most intense daily heat occurred at around 4 p.m. The annual average precipitation was 33.22" with an average snowfall of 2.70".

Selection and Description of Schools

The two schools selected for this comparative case study were chosen for the ability to control extraneous variables. School A used renewable energy systems in its design, and School B was designed using all traditional energy systems. Both schools were designed and both contracts administered by the same architectural firm. The schools were located in the same school district, built at the same time, and opened for occupancy at the same time in July, 2000. Both were elementary schools, had the same operating hours, and were located within approximately 2 miles of each other within relatively new residential neighborhoods. Similar locations eliminated the differences due to different climatic conditions.

School A had a gross square footage of 69,788 square feet, and School B had a gross square footage of 69,052 square feet. Both schools were designed for an occupancy of approximately 680 K-5 students. School A's design contained three finger classroom wings extending from a central main building. The classroom buildings were oriented on the site in a North/South exposure. School B's design was more compact with a single central building in a T-shape design. The school was oriented in a North/South exposure on the site. School A's design had 12 exterior walls and School B had 7. The difference of additional exterior walls increased the solar heat gain through the exterior walls of School A over School B. School A's solar heat gain was also increased by the additional glass of the light monitors necessary for daylighting, and by

the south exposure of those windows. School A also utilized clerestories for daylighting. The additional solar gain in School A required an additional 78 tons of HVAC over School B. School B's windows were much smaller and reduced significantly in number over School A, reducing the solar heat gain design criteria to 174.5 tons of HVAC. The building envelop of both schools were various combinations of cavity wall construction. Some areas utilized concrete block, air space, rigid insulation, and face brick, while others utilized metal stud, air space, rigid insulation, and face brick. Roofing for School A was a combination of modified bitumen and metal roofing, and roofing for School B was asphalt shingle. Both schools utilized a gutter system, with School A's channeled into a cistern system to provide irrigation water for the site.

Description of Energy Systems, School A

The main mechanical system for School A was a DX split system heat pump, roof mounted, with one for each classroom. The total BTU tonnage for the school was 252.5 tons. The heating and cooling function was included in the same unit with heat supplied by electrical heat strips, which was common for the heat pump. As stated in Chapter 2, these systems were moderate to high energy users with a typical life span of 15 to 20 years. The seasonal energy efficiency ratio, or SEER as it is commonly known, was rated at 10 on these units, which was a minimum rating as an industry standard. These units would tend to be high energy users as compared with units with a 12 or 16 SEER rating. Ventilation was the required American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard of 15 cubic feet per minute for schools. The school was also equipped with Direct Digital Controls (DDC), which allowed for a central operation of the HVAC system. The thermostats located in individual classrooms only allowed a 2-degree variance from the centrally controlled temperature setting via the

central controls. While the original design for the mechanical system was the use of geothermal heat pumps (see Chapter 2), the geothermal was deleted after the first bidding because of its higher initial cost over the DX split system by $362,000.

School A's lighting system was provided by daylighting, a renewable energy source. Natural lighting was provided by a series of light monitors located on the classroom buildings, cafetorium, and main corridors, with clerestories in the main entry lobby and library. The light monitors faced the South exposure. The light monitors were equipped with motorized shades so the instructor could darken the room if necessary. Light baffles in the light monitors diffused the natural light so that the light was dispersed equally around the room. A backup lighting system composed of energy efficient, high-frequency lamps and ballasts with lighting controls served the school on cloudy days or at night. The automatic lighting controls with sensors provided appropriate lighting conditions. The light switch in each room allowed teachers/administrators to manually turn off/on the lights. Occupancy sensors on a time delay would turn off all lights when areas were unoccupied.

Additionally, the school was originally designed for a solar photovoltaic system that would produce 5 kW into an integrated grid system. This system was deleted after the first bidding because of its initial cost. A solar energy system for domestic hot water for the school's kitchen was provided and consisted of six roof collectors, but this system was a direct heat and did not provide for any energy storage via a storage battery, nor was it connected to the grid system. It was not usable on cloudy days. A traditional gas hot water heater was also installed and served as the backup for hot water supply.

As part of the original design this school was to have a cistern rainwater collection system in providing a captured rainwater supply for irrigation and water for toilets. Power was to be supplied by wind energy (windmill) that would not only

circulate the water in the storage tanks but also power the pump that would fill the system from an underground well if there was insufficient rainwater. The city would not grant a permit for the well, so the windmill served only as a means of circulating the water in the storage system and produced no electrical power. The city also would not permit the use of the cistern water for toilet flushing. If additional water was needed, it was supplied by a city water feed on a day-to-day basis. An eco-pond was installed at the school for an environmental teaching model. While other sustainable features such as natural landscaping (xeriscaping), materials, and finishes were included in the school's overall design, they were not included here because they were not energy related.

Description of Energy System, School B

The main mechanical system used in School B was the same system used in School A with the exception that its SEER rating was 12, making it more energy efficient, and had a reduced tonnage of only 174.5 tons. The solar heat gain was less in School B primarily due to the lack of south facing light monitors for the daylighting and the reduced number of exterior walls. The ventilation was the same, and this school also had the same DDC controls and 2-degree variance thermostats. The lighting system was the same system used as the backup system used in School A. Domestic hot water was supplied by the traditional hot water heater, and this school did not use any of the other renewable energy systems utilized in School A. School B was a traditional, primarily electrically powered school, although both schools utilized natural gas for cooking in the kitchen cafeteria.

Selection and Description of Participants

The collection of data to answer the qualitative question of efficacy was acquired from the responses of the participants in this study. The administrative tiers were chosen

because of the positions of authority they held and involvement in the design, construction, maintenance, and operations of the schools. The school administrators (principals) were chosen because of the positions they held. The teachers were chosen by their respective principals, and all had occupied their respective schools for a minimum period of one full school year. The participants represented the three tiers of occupants for the purpose of triangulation. The first tier represented district administration and was the Assistant Superintendent for Facilities and the Director of Maintenance. The second tier was the two principals, which represented the school administration perspective. The third tier was comprised of three teachers from each school and represented the individuals who occupied random individual rooms from various locations within each school. As stated previously, the number of classroom teachers was limited to three from each school so as not to interrupt the instructional process.

Description of Interview Questions

Data were collected from interviews using a prescribed set of questions. The district administrators were asked both the quantitative and qualitative questions; the school administrators and teachers were asked only the qualitative questions. The qualitative questions were directed to the respondents representing the three levels of users of the facilities: district administrators, school administrators, and classroom teachers. These data were used to answer the efficacy question. The protocol used in this case study minimizes the inherent bias in interpretation by a single group.

Quantitative Questions

1. What was the initial cost of construction for the energy systems for School A and School B?

2. How many maintenance calls on the energy systems have occurred in the last 12 months for School A and School B? What work was required, its duration and cost to complete?

3. Do you have a regular maintenance schedule for the equipment in either school?

4. What routine maintenance is required for either system, such as filters?

5. What is the cost for maintenance for the last 12 months for both School A and School B?

6. Do you have a copy of the utility bills for the last 12 months on both School A and School B?

7. Are there any miscellaneous costs that you have incurred on either system in the last 12 months?

8. Have any parts been replaced on either system in the last 12 months?

9. Are there any operations costs that you have incurred in the last 12 months in School A or School B that were related to the equipment?

10. May I contact the manufacturers of the equipment in both schools to find out what is their anticipated service life of the equipment and their recommended maintenance schedule?

Qualitative Questions

1. Has either system failed to function in the last 12 months due to the breakdown of the equipment?

2. If so, what conditions occurred and did this interfere with the operation of the school?

3. Have you had to close the school anytime in the last 12 months due to equipment failure?

4. Has anyone in the school ever chronically complained about the comfort level of the schools in terms of heating, air conditioning, or lighting?

5. Have you had any ventilation problems in the last 12 months with either system?

6. Are you able to consistently maintain the correct temperature and lighting levels with either system?

7. Overall, are you pleased with the systems in School A or School B?

8. What changes would you make in either system after considering the last 12 months of occupancy?

9. Would you want this energy system installed in another school?

10. If not, what system would you install?

Collection of Quantitative Data

These data consisted of collecting the necessary documents and information for establishing the cost data. Initial costs were collected from the contractor's schedule of values, which defines the cost of construction by categories, and by the construction contracts. Maintenance and operations cost were collected from the district's archival information on both schools and consisted of the utility bills for the first 12-month operation period and maintenance records. Manufacturers recommendations for life span of the equipment for replacement requirements was procured from telephone interviews, manufacturers specification sheets, and previous research by others.

Collection of Qualitative Data

These data were collected from on-site interviews with the three tiers of participants. The interviews with district administrators were held in a joint meeting with the researcher, administrative personnel, architects, mechanical engineers, and respective contractors for the two school projects. The school administrator tier and the teachers were all interviewed at their respective schools. All the interviews were tape recorded (with participant approval), while the researcher simultaneously took notes to insure accuracy of the data.

Treatment of Data

These data were assembled into separate tables that can be found in Chapter 4. The quantitative data were used to determine the life cycle cost based on a 50-year life

span using the standard present value formula. The quantitative data were reviewed, and any subsequent clarifications needed were obtained from telephone interviews with both the architect and mechanical engineer. The qualitative data were rewritten and reviewed from subsequent replaying of the tape recordings and rereading the researcher's notes. Checking and rechecking between the notes and tape recordings verified the accuracy of the transcription of the data. During the analysis process, themes, patterns, and similarity of responses were recorded and were analyzed based upon the number and percentage of like and different responses made by the participants within their separate tiers. Separate percentages from the three tiers were then compared and an overall percentage was determined. Based upon the overall percentage, the researcher drew conclusions as to the positive or negative interpretation of the data and the establishment of efficacy as determined from the participants responses.

Quality of the Case Study

According to both authors in the case study method, reliability and validity are the two criteria for judging the quality of a case study (Stake, 1995; Yin, 1989). Validity and reliability in case studies are interlinked—establishing validity would simultaneously achieve reliability. Accurate interpretation of the data would establish validity, and accurate interpretation would be established by the use of triangulation. As a final procedure to insure the accuracy of the interpretation, a draft of the case study was presented to the school administration.

Reliability can be established by the ability to produce the same results following the same procedures. The techniques used in establishing validity are the same techniques for establishing reliability. Accuracy of the interpretation of the data,

accurate recording, triangulation and minimizing researcher bias, and following the same procedures as used here would produce the same results.

Summary

A case study was used in order to understand the specifics of a particular or unique situation. The use of the method of comparison and both quantitative and qualitative questions were exercised in order to deepen that understanding. The selection of the particular schools was to minimize the extraneous variables by choosing schools that had more similarities than differences, with the exception of the use of sustainable renewable energy sources, which was the focus of the study. The description of those schools was to illustrate the similarities/differences and establish a mental picture of the two subject schools. The selection and description of the participants also was to illustrate those who were involved and occupied the schools. The demographics of the district, schools, and geographical environment were to clarify the contextual environment of the two schools. The description of the energy systems was to establish exactly what was being compared in this study and to illustrate the similarities and differences between the two systems. The collection of data and the treatment of data were defined for replication and methodological correctness. The defining of the how to establish the quality of a case study was for those unfamiliar with the research method and to illustrate again methodological correctness. Providing a detailed description in methodology allowed reviewers to track the theoretical construct that was established in analyzing the results of the data.

CHAPTER 4
RESULTS

Analysis of Quantitative Data

It was the purpose of this study to test the theory for appropriate utilization of sustainable renewable energy systems in educational facilities in anticipation of providing the needed documentation to support a policy change in the design and construction of educational facilities. In order to accomplish this, two schools, School A and School B, were examined to ascertain and document differences between the cost and efficacy of the energy systems utilized in the two schools: one with renewable energy sources and the other with nonrenewable energy. The primary resistance to sustainable renewable energy systems had been their relatively high initial cost; when considered in terms of their life-cycle cost, would a different picture appear? Cost, however, was only one factor. Equally important was how well the systems functioned on a day-to-day basis. Interruptions in instruction due to an uncomfortable environment would certainly negate quickly any cost benefits.

The two schools selected for this comparative case study were chosen for the ability to control extraneous variables. School A used renewable energy systems in its design, and School B was designed using all traditional energy systems. Both schools were elementary schools, designed by the same architectural firm, and were located within approximately 2 miles of each other in relatively new residential neighborhoods. School A had a gross square footage of 69,788 square feet, and School B had a gross square footage of 69,052 square feet; both were designed for an occupancy of

approximately 680 K- 5 students. School A's design contained three finger classroom wings extending from a central main building. School B's design was more compact with a single central building in a T-shape design. Both schools were oriented in a North/South exposure on their sites.

The construction of any building was an integrated consideration where items or systems were not separate from but reliant upon each other. The construction of the building envelop did have an impact on energy consumption, and those costs were incurred in the initial contract price of the school. However, for this study the initial costs of the energy systems themselves were extracted out of the contract price and used as the initial costs in order to focus on the life cycle cost of the energy systems alone. The maintenance, operations, and replacement costs were those costs incurred by the various energy consuming systems. For the purpose of this study, the costs were as close as could reasonably be assessed or anticipated by the collected data and from the interviews with the project professionals and manufacturers of the various equipment. Accuracy of the costs was reliant upon the accuracy of the data supplied to the researcher. All initial costs were rounded to the nearest hundred. Calculations (as previously stated) were based upon an inflation rate of 3% and a discount rate of 0%. The number of years for replacement was dependent on the type of system and the information from the collected data. Operations and maintenance costs were calculated in 10-year periods over the service of the schools. The service life cost was the total cost over the 50-year life span of the system. All costs are in year 2000 dollars.

Table 1 illustrates the initial costs for construction of School A and School B. School A's initial construction cost slightly over $1.4 million over School B, increasing the square foot cost for School A at $21 over School B.

Table 1. Initial Construction Costs of Schools

	School A	School B
Total original contract	$9,290,000	$7,850,000
Change order for technology addition	$803,481	$715,088
Total contract	$10,093,481	$8,565,088
Cost per sq. ft.	$145	$124

Table 2 clarifies the initial construction costs for the energy systems in School A and School B. Even though the schools were the same approximate size, the mechanical system initial cost was more for School A due to the additional tonnage required for the increased heat loads. The cistern initial cost in School A should be compared to the irrigation system initial cost in School B.

Table 2. Initial Construction Costs of Energy Systems

School A		School B	
Mechanical HVAC	$692,000	Mechanical HVAC	$519,400
Electric lighting	$419,300	Electric lighting	$340,200
Daylighting	$500,000	Gas H/W	$45,000
Windmill	$13,000	Irrigation System	$42,400
Cistern	$112,000		
Solar Hot Water (H/W)	$25,000		
Gas H/W	$45,000		

Table 3 contains the maintenance costs for the mechanical systems in School A and School B. These costs were taken from the maintenance work orders and from the routine scheduled maintenance as delineated by the director of maintenance for the school district. School A showed a lower overall maintenance cost for the mechanical systems of almost $100,000 over School B for the service life period.

Table 3. Mechanical Maintenance Costs

	School A		School B	
Year	Cost	Type	Cost	Type
0	$5100.00	Initial	$6000.00	Initial
10	$58,465.78	Yrs. 0-10	$68,783.28	Yrs. 0-10
20	$76,284.55	Yrs. 11-20	$89,746.58	Yrs. 11-20
30	$99,533.99	Yrs. 21-30	$117,098.94	Yrs. 21-30
40	$129,869.24	Yrs. 31-40	$152,787.60	Yrs. 31-40
50	$169,449.89	Yrs. 41-50	$199,353.19	Yrs. 41-50
Service Life NPV	$533,603.46		$627,769.60	

Table 4 depicts the maintenance costs for the electric lighting systems in School A and School B. The higher maintenance costs in School B are reflective of the increased usage of the electric lighting system in School B over School A. The daylighting system in School A was the primary lighting system for the school resulting in less usage of the electric lighting system and consequently lower maintenance costs.

Table 4. Electric Lighting Maintenance Costs

	School A		School B	
Year	Cost	Type	Cost	Type
0	$500.00	Initial	$1000.00	Initial
10	$5,731.94	Yrs. 0-10	$11,463.88	Yrs. 0-10
20	$7,478.92	Yrs. 11-20	$14,957.73	Yrs. 11-20
30	$9,758.28	Yrs. 21-30	$19,516.45	Yrs. 21-30
40	$12,732.36	Yrs. 31-40	$25,464.60	Yrs. 31-40
50	$16,612.88	Yrs. 41-50	$33,225.53	Yrs. 41-50
Service Life NPV	$52,314.38		$104,628.19	

Table 5 is the maintenance costs for the windmill in School A. Routine maintenance consisted of changing two quarts of oil in the pump annually and the checking of bolt connections for tightness. The costs were for the oil and the associated labor charge for installing the oil and checking the bolt connections. The overall

maintenance costs for the windmill totaled only $2,092. for the 50 year life of the school, making it very cost effective in terms of maintenance.

Table 5. Windmill Maintenance Costs

School A	Year	Cost	Type	Service Life NPV
	0	$20.00	Initial	
	10	$229.28	Yrs. 0-10	
	20	$299.21	Yrs. 11-20	
	30	$390.35	Yrs. 21-30	
	40	$509.34	Yrs. 31-40	
	50	$664.56	Yrs. 41-50	$2,092.73

Table 6 contains the maintenance costs for the cistern system in School A and for the traditional irrigation system in School B. The cistern maintenance costs were for the annual treatment of algae buildup in the tank and piping and checking connections in the piping system. The irrigation system maintenance costs consisted of sprinkler head and piping repairs on as needed basis. These costs were taken from the maintenance work orders from the two schools and from manufacturers recommendations.

Table 6. Cistern Maintenance Costs

	School A		School B (irrigation)	
Year	Cost	Type	Cost	Type
0	$100.00	Initial	$1000.00	Initial
10	$1,146.39	Yrs. 0-10	$11,463.88	Yrs. 0-10
20	$1,495.81	Yrs. 11-20	$14,957.73	Yrs. 11-20
30	$1,951.73	Yrs. 21-30	$19,516.45	Yrs. 21-30
40	$2,546.59	Yrs. 31-40	$25,464.60	Yrs. 31-40
50	$3,322.69	Yrs. 41-50	$33,225.53	Yrs. 41-50
Service Life NPV	$10,463.20		$104,628.19	

Table 7 shows the maintenance costs for the gas hot water systems in both School A and School B. Maintenance costs were extracted from the maintenance work orders for both schools for the year, the district's director of maintenance, and from the manufacturers. The gas hot water systems were identical in both schools and, therefore,

the maintenance costs are the same. There were no maintenance costs for daylighting or the solar H/W according to the manufacturer nor were there any maintenance work orders from the school.

Table 7. Gas Hot Water Maintenance Costs

Schools A & B	Year	Cost	Type	Service Life NPV
	0	$300.00	Initial	
	10	$3,439.16	Yrs. 0-10	
	20	$4,487.31	Yrs. 11-20	
	30	$5,854.95	Yrs. 21-30	
	40	$7,639.41	Yrs. 31-40	
	50	$9,967.73	Yrs. 41-50	$31,388.56

Table 8 illustrates the operations costs for the mechanical systems in School A and School B. The mechanical system in School A used heat pumps with a lower SEER rating than those in School B, making them less energy efficient. This lesser efficiency constituted a higher usage of electricity and consequently, higher costs. This amounted to an additional $600,000 in operation costs for School A over School B.

Table 8. Mechanical Operations Costs

	School A		School B	
Year	Cost	Type	Cost	Type
0	$44,500.00	Initial	$38,800.00	Initial
10	$510,142.63	Yrs. 0-10	$444,798.52	Yrs. 0-10
20	$665,620.46	Yrs. 11-20	$580,361.18	Yrs. 11-20
30	$868,483.78	Yrs. 21-30	$757,239.70	Yrs. 21-30
40	$1,133,174.32	Yrs. 31-40	$988,026.06	Yrs. 31-40
50	$1,478,535.49	Yrs. 41-50	$1,289,149.90	Yrs. 41-50
Service Life NPV	$4,655,956.68		$4,059,575.36	

Table 9 depicts the operations costs for the electric lighting systems in School A and School B. School A consistently showed a higher electrical usage per month over School B which is illustrated by the higher operation costs. School A's primary lighting

system was daylighting with the electric lighting system utilized only as a backup system. The higher operation costs showed that the electric lighting system was being used more than should have been necessary.

Table 9. Electric lighting Operations Cost

	School A		School B	
Year	Cost	Type	Cost	Type
0	$34,600.00	Initial	$30,200.00	Initial
10	$396,650.22	Yrs. 0-10	$346,209.16	Yrs. 0-10
20	$517,538.55	Yrs. 11-20	$451,724.42	Yrs. 11-20
30	$675,270.41	Yrs. 21-30	$589,397.91	Yrs. 21-30
40	$881,074.67	Yrs. 31-40	$769,030.59	Yrs. 31-40
50	$1,149,602.63	Yrs. 41-50	$1,003,410.49	Yrs. 41-50
Service Life NPV	$3,620,136.49		$3,159,772.57	

There were no operations costs for the solar H/W, daylighting, or windmill. The monthly utility bills for electricity, gas, and water were total usage for each school for the month. The total electricity, gas, and water usage for the year for each school was divided by percentage and allocated to the individual systems based upon industry standards of usage. The mechanical systems were allocated 45% of the total electrical usage with 35% allocated to the electric lighting systems. The remaining 20% was for other uses not covered in this study. The gas hot water was allocated 30% of the total gas usage, with the remaining 70% for other uses not covered in this study.

Table 10 shows the operations costs for the irrigation water utilized by the cistern in School A and the traditional irrigation system in School B. The operation costs for the cistern consisted of the cost for the city water for refill purposes when there was insufficient rainwater available. These costs would not have existed had the school been granted a well permit and refilled the cistern with their own well water. Potable city water was not necessary for irrigation purposes. The higher operation costs for School

B's irrigation system was the total reliance on city water for its irrigation needs, almost doubling the operation costs over that of School A's cistern system.

Table 10. Irrigation Water Operations Costs

	School A (Cistern)		School B (No Cistern)	
Year	Cost	Type	Cost	Type
0	$1500.00	Initial	$2800.00	Initial
10	$17,195.82	Yrs. 0-10	$32,098.86	Yrs. 0-10
20	$22,436.64	Yrs. 11-20	$41,881.73	Yrs. 11-20
30	$29,274.73	Yrs. 21-30	$54,646.16	Yrs. 21-30
40	$38,196.88	Yrs. 31-40	$71,300.85	Yrs. 31-40
50	$49,838.27	Yrs. 41-50	$93,031.44	Yrs. 41-50
Service Life NPV	$156,942.35		$292,959.05	

Table 11 is the operations costs for the gas hot water systems in both School A and School B. These costs were taken from the gas utility bills for both schools. The higher operation cost for School A was due to a higher usage of gas over School B. The gas hot water system in School A was to be used only as a backup system with the solar hot water system as the primary provider for hot water. It was undeterminable why School A was using more gas since the gas hot water was not metered separately.

Table 11. Gas Hot Water Operations Costs

	School A		School B	
Year	Cost	Type	Cost	Type
0	$700.00	Initial	$500.00	Initial
10	$8,024.72	Yrs. 0-10	$5,731.94	Yrs. 0-10
20	$10,470.43	Yrs. 11-20	$7,478.88	Yrs. 11-20
30	$13,661.54	Yrs. 21-30	$9,758.24	Yrs. 21-30
40	$17,825.21	Yrs. 31-40	$12,732.29	Yrs. 31-40
50	$23,257.86	Yrs. 41-50	$16,612.76	Yrs. 41-50
Service Life NPV	$73,239.76		$52,314.12	

Water usage for irrigation was allocated as a percentage of the total water usage in both schools and set at 30%. In its first year of operation School A experienced a major underground leak in its water piping system in the months of October and November, accounting for a $3500 charge for the two months. Since this was a rare occurrence the researcher did not feel it was indicative of the normal water usage that would have been utilized by School A. The $3500 was subtracted from the total yearly usage cost and an average monthly usage was calculated from the remaining months of normal usage. That average was used for the two months in which the underground leak occurred. The researcher felt this gave a more accurate picture of the actual water usage. The water allocation for School A for irrigation was the city water necessary to refill the cistern storage tanks in the absence of an adequate amount of rain. As previously noted, the city would not grant a permit for a well to refill the cistern and city water had to be used. It was originally intended for the cistern to be refilled by well water pumped by the windmill eliminating the requirement for city water and operation costs.

The column designated year in all replacement cost tables (Tables 12-15) was the year of the necessary replacement. The initial cost in the year 0 was shown for clarification of the initial cost used in the calculations; no costs were spent in year 0.

Table 12 shows the replacement costs for the mechanical systems in Schools A and B. Included in the initial costs for the mechanical systems were air handlers, condensers, fans, controls, testing and balance costs, and labor. Piping typically is not replaced but repaired as a matter of maintenance, and therefore, is not included in the replacement costs.

Table 12. Mechanical Replacement Costs

	School A		School B	
Year	Cost	Type	Cost	Type
0	$380,600.00	Initial	$285,700.00	Initial
15	$592,962.40	Replacement	$445,111.29	Replacement
30	$923,816.10	Replacement	$693,468.89	Replacement
45	$1,439,275.38	Replacement	$1,080,401.94	Replacement
Service Life NPV	$2,956,053.88		$2,218,982.11	

Table 13 contains the replacement costs for the daylighting system in School A. These costs consisted of the replacement of the fabric baffles in the light monitors and the shades necessary to darken the monitor windows as necessary. There were no other replacement costs for the daylighting system.

Table 13. Daylighting Replacement Costs

School A	Year	Cost	Type	Service Life NPV
	0	$112,400.00	Initial	
	20	$203,006.90	Replacement	
	40	$366,653.04	Replacement	$569,659.94

Table 14 delineates the replacement costs for the cistern system in School A. The replacement costs consisted of replacement of the storage tank and the associated installation labor. The service life of the tank was based upon the manufacturer's recommendation.

Table 14. Cistern Replacement Costs

School A	Year	Cost	Type	Service Life NPV
	0	$36,000.00	Initial	
	20	$65,020.00	Replacement	
	40	$117,433.35	Replacement	$182,453.35

Table 15 is the replacement costs for the gas hot water systems in both School A and School B. These systems were the same in both schools and therefore, the replacement costs are the same. These costs were for replacement of the tanks and associated labor costs, the piping was excluded since it typically is not replaced, but repaired on an as needed basis. Repair costs are covered under maintenance costs.

Table 15. Gas Hot Water (H/W) Replacement Costs

School A & B	Year	Cost	Type	Service Life NPV
	0	$40,000.00	Initial	
	15	$62,318.70	Replacement	
	30	$97,090.50	Replacement	
	45	$151,263.84	Replacement	$310,673.04

There were no replacement costs for the windmill, electric lighting, or the solar H/W. The windmill according to the manufacturer had a service life of 50 plus years if the required yearly maintenance was done. The solar H/W also had a service life of 50 plus years, according to the manufacturer.

There were no replacement costs for the electric lighting system. It was not typical for a school to completely replace the entire lighting system. Replacement of lamps, ballasts, lenses, switches, dimmers, and motion sensors was considered a maintenance item, and those costs were included in the maintenance costs for both schools. Also there were no replacement costs for the irrigation system in School B. Similar to the electric lighting system, it was not typical to replace an entire system but to replace piping, sprinkler heads, or timers on an as needed basis under maintenance costs.

The initial replacement costs were different than the initial costs of the systems because it was not typical to replace the entire system. Catastrophic failure of an entire system would only occur from a natural disaster and not from normal operation. Piping,

raceways, duct work, grills, registers, duct insulation, switchgear, and wiring did not require replacement in the same time frame as the moving or operational parts of the systems; repair or replacement of those items was typically done as needed as part of systems maintenance. The replacement costs associated with the daylighting system were the baffles and shades, which were made of fabric and would deteriorate with exposure to the direct sunlight (see Table 13). Replacement of the storage tanks only was required in the cistern system. The gas hot water tanks and associated labor costs in both schools required replacement but not the piping (see Table 15).

Table 16 shows the calculation of the life cycle cost of all the energy systems at NPV for both School A and School B. The analysis of the total life cycle cost of all the energy systems at NPV in School A and School B showed an increased cost of $3,051,586 for School A over School B over their 50-year service life (Table 16). This difference would calculate to an increase in cost for School A of $61,032 per year for 50 years over School B. The present configuration of the energy systems in School A was not more cost effective than the traditional configuration of the energy systems in School B.

Analysis of Interview Data

These data were used to answer the second question of this study. When in place was the performance of the renewable energy systems equal to the traditional systems in delivering a comfortable instructional environment for the occupants. The responses of the three tiers of participants, district administrators, school administrators, and classroom teachers were as follows and were related to any of the energy systems in the schools.

Table 16. Life Cycle Cost of Energy Systems at NPV

	School A					School B				
	Initial	Mainten-ance	Operations	Replace-ment	Total	Initial	Mainten-ance	Operations	Replace-ment	Total
Mechanical	$692,00	$533,603	$4,655,957	$2,956,054	$8,837,614	$519,400	$627,770	$4,059,575	$2,218,982	$7,425,727
Electric Lt.	$419,300	$52,314	$3,620,136	0	$4,091,750	$340,200	$104,628	$3,159,773	0	$3,604,601
Daylighting	$500,000	0	0	$569,660	$1,069,660	0	0	0	0	0
Windmill	$13,000	$2,093	0	0	$15,093	0	0	0	0	0
Cistern	$112,000	$10,463	$156,942	$182,453	$461,858	0	0	0	0	0
Irrigation	0	0	0	0	0	$42,400	$104,628	$292,959	0	$439,987
Solar HW	$25,000	0	0	0	$25,000	0	0	0	0	0
Gas H/W	$45,000	$31,389	$73,240	$310,673	$460,302	$45,000	$31,389	$52,314	$310,673	$439,376
Total Life Cycle Cost of all energy systems at NPV					$14,961,277					$11,909,691

Question #1

Has either system failed to function in the last 12 months due to the breakdown of the equipment? The response from the district administrators was no, from the school administrators the responses were divided with School B responding yes and School A responding no. The classroom teachers in School A all responded yes, with teachers in School B divided with 2 responding yes and one no. The differences in responses appeared to be due to how each defined what "failed to function" meant to them and how closely it impacted them on a personal basis. The district administrators did not interpret adjustments in rebalancing of the systems to mean the systems had failed to function. Failed to function to them meant that the systems did not work at all. The school administrators were divided in their responses, with School A's administrator interpreting failed to function the same as the district administrators. School B's administrator defined failed to function as meaning any incident that had an adverse affect on room temperature in any room. The classroom teachers also were divided in their responses based on the same interpretations similar to the district administrators and the school administrators. It also appeared that when adjustments were necessary, if it was one of the participants' room or a room in near proximity to their room, they had a tendency to define it more as a function failure. School B's administrator also experienced repeated adjustments in 2 classrooms over a period of time; this repetition of the same problem appeared to define her interpretation as a fail to function.

Question # 2

If so, what conditions occurred and did this interfere with the operation of the school? The school administrator in School B had two classes that had to be moved to different rooms 5 or 6 times because their rooms were too hot at 80 degrees, clearly

indicating to her that this interfered with the operation of the school. Two of the classroom teachers in School B affirmed their school administrator's response and stated they had a general idea that some classes had to be moved, but this did not affect their rooms. One teacher, while responding yes to question #1, did respond in question #2 that there was a heating/cooling problem. She was uncertain as to what specifically it was and responded that it did not interfere with school operation. In School A all three classroom teachers had responded yes to question #1 in opposition to the response of their school administrator. One responded that, while there were some problems of areas being too hot, the building was always cold during the winter months and it appeared to her that there was not an even distribution of heat throughout the building. One classroom teacher responded that, while 2 or 3 times there were problems of too hot and too cold, these problems were only mildly distracting and appeared to her to affect teachers more than the students. The third teacher in School A responded that her room had become so hot on one occasion at 86 degrees she lost an afternoon of teaching because her students became too distracted, uncomfortable, and lethargic. She added that there were ongoing problems of her room alternating between too hot and too cold and she permanently changed rooms the following year. The district administrators and the school administrator in School A had all responded no to question # 1, so they had no response to question # 2.

Question #3

Have you had to close the school anytime in the last 12 months due to equipment failure? All three tiers of participants responded no to this question. None of the problems revealed in the previous questions were of such a nature as to warrant closing the school.

Question #4

Has anyone in the school ever complained chronically about the comfort level of the schools in terms of heating and air conditioning? Both district administrators knew there had been a few complaints due to the maintenance requested; with one believing the problem had been resolved and one indicating that they still had some minor adjustment problems due to individual comfort level preferences on the part of a few teachers. Both school administrators responded yes to this question. The school administrator in School B responded that the two classes mentioned in question #1 both had lots of ongoing problems and were not resolved. One teacher was permanently moved to another classroom. The school administrator in School A responded that a few rooms were too cool several times, but maintenance was very responsive and rectified the problem rapidly. All classroom teachers in both schools responded yes with some rooms being too warm and some too cool. From the responses, it appears that both schools suffered from a system balancing problem, which is not uncommon in new schools. It typically takes one full year to accurately adjust and balance the air flow through an entire school. Systems required adjustments to accommodate the temperatures variances from each seasonal change in the weather. It appears both schools were experiencing the same balancing issues.

Question # 5

Have you had any ventilation problems in the last 12 months with either system? All participants responded no to this question.

Question #6

Are you able to consistently maintain the correct temperature levels with either system? The district administrators, while recognizing there were initial balancing

problems, felt that they were able to maintain correct temperature levels due to the centrally controlled DDC systems in both schools. The school administrators were divided due to their individual experiences, with School B responding no, feeling further maintenance was required, and School A responding yes. All classroom teachers in School A responded no in opposition to their school administrator. Again, how directly an individual was affected by the temperature seems to correlate to their response, with the school administrator and the classroom teachers in School A having very different perceptions as to the impact of the temperature variations. The classroom teachers in School B were divided 2 to 1 with the one stating that her room was always fine. She saw the question relating only to her room and not the school as a whole. One of the teachers who responded no also remarked that the temperature problems seem to be more exacerbated during the time of seasonal weather transitions.

Question #7

Overall are you pleased with the system in School A or School B? Both district administrators responded yes along with the school administrator in School B. The school administrator in School A responded no even though she responded no to the first three questions. Her reason for responding no was explained as not liking the DDC controls and the system being centrally controlled. She wanted access to the controls so she could adjust the system as needed. All of the classroom teachers with the exception of one in School A answered yes to this question even though they had illustrated several of the problems that had occurred.

Question #8

What changes would you make in either system after considering the last 12 months of operation? This question was intentionally open ended in order to discover

what the participants felt was the primary problem. One district administrator had no explicit changes, the other preferred the higher SEER rating on the units in School B. Both school administrators wanted to have access to the controls at their individual schools, although both conceded that would not happen because central control was instituted for the purpose of energy management. They both felt they would have less problems if they had been able to control the systems in their schools directly. All of the classroom teachers from both schools felt the same way, that the control of the system should be located and operated at the school and not from a central office. They felt that someone located at a distance could not really assess the climate in individual rooms. In addition, one teacher from School B remarked that she would also like to receive feedback on a problem in order to have a written record established and kept on reoccurring problems. She also felt this would enhance clear communication to the occupants as to the nature of the problem. Two classroom teachers, one from each school, also indicated another reason why they did not like the central controls. The heating/cooling systems were shut off at approximately 4:15 p.m. at the end of school. They both were prevented from staying after hours to complete some work because their rooms no longer had heating or cooling and became uncomfortable. They felt the school should have the option to keep certain rooms heated or cooled for just such occurrences.

Question #9

Would you install this energy system in another school? Both district administrators answered yes, although no subsequent schools have as low a SEER rating of 10 like School A. Similarly, both school administrators also responded yes, with the school administrator from School A feeling that everyone should become energy

conscious. All classroom teachers from both schools also responded yes to this question, with one teacher from School A reiterating that the central DDC controls should be eliminated. Even with several problems and complaints, all participants felt that they would install these energy systems again, indicating to the researcher that the problems had all been manageable and not sufficient enough as to warrant the systems inefficacious.

Question #10

If not, what system would you install? Since all participants had answered in the affirmative to question # 9, the researcher decided to try and open the discussion to include some of the other energy systems. Although at the beginning of the interviews the researcher defined the energy systems to mean heating, air conditioning, ventilation, lighting, and water usage with only three of the questions directly addressing the mechanical systems, no participants had commented on the other energy systems until the researcher asked about the lighting.

Question #10 was then used for the participants' responses on how well they liked their lighting systems. While the district administrators did comment on the cistern system and solar H/W system in School A, neither the school administrator nor the classroom teachers from School A commented on those particular systems. Both the district administrators and school administrators from both schools were overwhelmingly favorable about the daylighting system. One of the district administrators felt that the daylighting was an impetus for teacher recruitment. The enjoyment of the atmosphere in the building made teachers want to come to teach at their schools.

The school administrator from School B had visited School A and gave a favorable response to the daylighting and would have liked to have had it in her school

instead of the artificial lighting system. The school administrator from School A felt she appreciated the daylighting over any other particular feature in her school and felt it was responsible for the positive attitude and mood exhibited by the students and the teachers on a daily basis. She also had the opportunity to visit School B and responded that it was very noticeable to her that she did not have the same mood elevation that she felt in her school.

The classroom teachers from School A unanimously reflected this same opinion. All responded that they also felt an elevation in mood and attitude in School A directly attributable to the natural daylighting. They all indicated that they felt the daylighting was having a very positive learning effect on their students and had also remarked that they felt the students had a more positive attitude. The classroom teachers from School B were split on their responses with 2 responding that the lighting in their school was fine, and one indicating that she would have preferred the natural daylighting that she had seen at School A. She felt that the artificial lighting was hard for the students. The other two made no response as to whether or not the lighting affected their students. (See table 17 for a summary of the responses to the qualitative questions.)

Perceived Efficacy of the Systems for School A and School B

The analysis of the overall percentages in conjunction with the interpretation of the descriptive responses, the systems appeared to have no difference in efficacy from the perception of the respondents. Although the mechanical systems in both School A and School B had experienced operational problems in their first year as indicated by the 100% affirmative response that there had been chronic complaints, there was an 80% affirmative response that the participants from all tiers were pleased overall with the mechanical systems in both School A and School B (see table 17).

Table 17. Summary of Responses on Qualitative Questions

Quest.	DA1	DA2	SAA	SAB	CT1A	CT2A	CT3A	CT1B	CT2B	CT3B	Yes%	No%
1	no	no	no	yes	yes	yes	yes	no	yes	yes	60%	40%
2	no	no	no	yes	yes	yes	yes	no	no	yes	50%	50%
3	no	no	no	no	no	no	no	no	no	no	0%	100%
4	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	100%	0%
5	no	no	no	no	no	no	no	no	no	no	0%	100%
6	yes	yes	yes	no	no	no	no	yes	no	no	40%	60%
7	yes	yes	no	yes	yes	yes	no	yes	yes	yes	80%	20%
8	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	90%	10%
9	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	100%	0%
10	yes	yes	yes	no	yes	yes	yes	yes	yes	no	80%	20%

DA1 and DA2 = district administrators
SAA = school administrator School A
SAB = school administrator School B
CT1A,CT2A,CT3A = classroom teachers School A
CT1B,CT2B,CT3B = classroom teachers School B

The participants were equally divided concerning whether the mechanical systems had interfered with the operations of the schools. The reason for this division appeared to be whether the participant was answering in terms of the entire school or the individual rooms. The mechanical problems did not interfere with the operation of the entire school but rather affected two or three classrooms on a reoccurring basis in both School A and School B. The problems seemed to be exacerbated by the fact that the school administrators and classroom teachers felt a sense of loss of control over their own systems in not having the ability to control their own temperatures as the needed. This was evident when out of the 90% affirmative response that the participants would make changes to either system, 80% commented that they would change who controlled the temperature settings in both School A and School B (see table 17). Even with this need to make some changes, 100% of the participants responded that they would install their respective energy systems in another school. From this perception of theparticipant's responses, the researcher concluded that there was no difference in the efficacy of the systems, with participants from both School A and School B equally satisfied or dissatisfied with the performance of their respective systems.

The lighting system in School A received unanimous affirmative responses by the district administrators, along with the school administrator and classroom teachers from School A. The responses from the School B participants were equally divided as to whether they liked the lighting system in School B. While two were satisfied with their artificial lighting system, two would have preferred the natural daylighting of School A. The perception of the respondents was that the mechanical and lighting systems in both School A and School B were equally efficacious.

The systems did produce their intended result and accomplished what they were required to do in respect to heating, cooling, ventilation, and lighting. While their operations were not perfect and there were problems that required repeated adjustments, the experiences for both schools were not out of the ordinary for any new school. The balancing of systems could take up to one year, and successfully accommodating individual temperature preferences would most likely never be accomplished regardless of the system.

The efficacy of the cistern system, irrigation system, windmill, solar H/W, and gas H/W was satisfactory with all the systems accomplishing their required operational duties. The performance level, or to what degree they were efficacious, is discussed in Chapter 5 under conclusions.

Summary

The analysis of the quantitative data in tabular form best illustrates the step-by-step process of assaying the life cycle cost of individual energy systems and subsequently the collective life cycle cost. It allowed for a detailed understanding of how each of the individual systems impacted and affected the overall life cycle cost. The descriptive paragraphs allowed for explanation of how the numbers were derived and calculated providing a map for replication of the research. The maintenance costs for the mechanical equipment in School B were higher than School A because there were more work orders for the mechanical equipment in that year. Although School A had more heat pump units that required a higher routine maintenance cost, the additional work orders not related to routine maintenance increased the initial cost of the maintenance for School B. These figures were a snapshot in time, and it would be highly likely that over time the maintenance costs for School B would not remain higher than School A.

The maintenance costs for the electric lighting in School A was less because the lighting was used less than School B because of the primary use of the daylighting in School A. Equipment would last longer due to less usage and require less maintenance.

The windmill maintenance costs were routine costs supplied by the manufacturer; the school experienced no work orders on the system. The costs were for an annual oil change and the labor to do it. The cistern maintenance costs were routine labor costs for checking the system components annually for any wear and periodic treatment for any algae problem in the storage tanks or piping. The maintenance costs for the gas H/W were routine costs for annual checks and from work orders generated during that year.

The operational costs for all systems came from the utility bills generated by both schools during that year. The costs were allocated to each system as previously delineated in the paragraphs preceding the operational cost tables. The mechanical operations costs for School A were higher than School B, primarily due to the higher tonnage requirement for the school and the lower SEER rating of the heat pumps. Any system requiring more tonnage and producing at a lesser efficiency capacity would consume more energy. Had the SEER rating been equal to that of the units in School B, the operational costs would have in all likely hood been lower.

The cistern operation costs came from the required supplement of city water for irrigation. While there was a substantial savings over School B, the cistern was not able to achieve an optimum life-cycle cost because the system relied upon city water to make up any deficit of water. Further discussion can be found in Chapter 5 under conclusions.

The operations costs for the Gas H/W were derived from the previously stated percentage of the gas utility bills. In theory the operations costs for School A should have been less due to the presence of the solar H/W system that was the primary system

for heating the hot water. The researcher was not able to ascertain from any sources why School A was still utilizing more gas than School B.

What components constituted the initial costs for the replacement costs were described in detail following the tabular analyses. The life spans of the equipment came from related research and from the manufacturers of the equipment.

The life cycle cost of the energy systems were all calculated at NPV so there was an equitable comparison among the systems. The life cycle cost of School A was a little over $3 million over that of School B, this amount would occur over the 50-year service life of the schools. It appeared that in the particular configuration of the sustainable renewable energy systems and the traditional systems in School A and School B in this case study the sustainable renewable energy systems were not a cost effective option for reducing energy costs in the educational facilities in this case study.

In order to answer the efficacy question, the researcher conducted an oral survey and asked questions to a selected group of respondents. The questions were limited to those posed by the researcher and, therefore, restricted the answers of the respondents. The responses were limited to those perceptions of the selected group in this study. Their knowledge of sustainable renewable energy systems and traditional energy systems and how they functioned would also have inherent limitations in answering the questions. The analysis of the qualitative data was illustrated in both a descriptive form and a tabular form. The descriptive form was included to better understand the perceptions of the respondents. It appeared that in this particular configuration in this case study the efficacy of the sustainable renewable energy systems and the traditional energy systems was equal.

In consideration of the above findings, the two research questions were answered accordingly:

1. Sustainable renewable energy systems, when considered in the context of the life cycle methodology, were not more cost effective than the traditional energy systems in the configuration in this case study.

2. When in place their performance was equal to the traditional systems in delivering a comfortable instructional environment for the occupants.

Therefore, it appeared sustainable renewable energy systems, in this case study, are not a cost effective option for reducing energy costs in educational facilities and their efficacy is equal to traditional energy systems.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Introduction

The United States Department of Energy forecasted that by the year 2010 it would be necessary to build 6000 plus new schools in order to satisfy the current demand for student stations (USDOE, 1999). Since 54% of all energy consumption in the U.S. was used to operate buildings, the current energy crisis would be exacerbated by new school construction (Florida Department of Education, 1999; Mastaitis, 1999). Energy was not free and was costing U.S. schools $6 billion annually in order to supply their energy needs. The U.S. Department of Energy *estimated* that at least 25% or $1.5 billion could be saved annually by utilizing current energy saving technology found in sustainable renewable energy systems (Energy Smart Schools, 1997). Rising energy costs were resulting in a disproportionate drain on school financial resources and had created a need for a reexamination of the traditional energy systems used in educational facilities (American Association of School Administrators, 1992; Castaldi, 1994; Gaul & Kynell, 1980; Thomason, 1986). Legislatures and local school boards had been focused on the initial cost of construction of educational facilities, without examining the long-term impacts of energy efficiency, future energy supplies, high maintenance and operations costs, replacement costs, and environmental impacts (Florida Department of Education, 1999).

In this study, the design and construction of School A was an attempt to reduce the rising operational costs of the district's schools. The goal was to design the most energy efficient, cost effective school facility. School A was promoted as the most comprehensive sustainable school in the U.S. and was intended by design to save $50,000 per year on energy costs. The daylighting was to substantially decrease utility bills by reducing the heat gain that was typical with artificial lighting and by minimizing the use of the artificial lighting all together. The windmill was to produce cost-free energy for circulation of the stored rainwater, and the cistern was to supply the water necessary for irrigation, drastically reducing the monthly water bills. The solar H/W system was intended to supply the majority of the school's hot water needs and subsequently reduce the electrical bill. The backup hot water was supplied by gas energy. While a geothermal mechanical energy system was the original intended system for heating/cooling, due to the much higher initial cost received on the bid, the system was replaced by the existing traditional split DX system heat pumps. The estimated increased initial cost for School A over the district's traditional school designs (School B), was projected at 15%, but it was expected that the savings on the maintenance and operations costs would more than make up the difference providing a payback in 4 to 5 years. The actual increase was 18%. The sustainable features, along with the theoretical reasons behind them, were intended to become part of the curriculum and learning process for the students who occupied the schools. While the later did occur, School A was not the energy efficient school it was anticipated to be and the analysis of the data shows that School A in actuality was less cost effective than the traditionally designed School B. The life cycle cost analysis showed that School A would cost more than $3 million over School B over a 50-year service life. While the $3 million could be reduced

with fluctuations in costs for maintenance and operations by replacing the low 10 SEER rated heat pumps with more efficient equipment at replacement times, School A had not shown to date a $50,000 per year reduction on energy costs. Since the construction of a building, especially a school, was a complicated and integrated process, it was and continues to be, difficult to isolate one factor that can be determined to be the cause of a particular problem. In analyzing the design, data, through lengthy interviews with design professionals and manufacturers, and studying related literature the findings showed that School A consistently used more energy than School B, indicating that the sustainable renewable energy systems did not appear to be more cost effective in this case. The additional tonnage of heating and cooling combined with the use of less energy efficient equipment in School A would not use less energy. This particular configuration was not going to achieve the goal of the school district, which was to be the most energy efficient and cost effective school facility. In this particular case and configuration, the actuality did not support the theory. The life cycle cost of the daylighting was, in itself, a little over $2 million less than the electric lighting system in School B and $3 million less than School A, which made it more cost effective over both artificial lighting systems; however, due to its configuration in this case, it had a negative affect on the operation cost of the mechanical system by increasing the heat loads. The cost of the electrical lighting system for backup also had to be considered in terms of the integrated life cycle cost of the need to have two complete systems for lighting. While the daylighting was cost effective in itself, it had a detrimental effect on the energy savings and life-cycle cost of the mechanical system in School A, resulting in an increase of $1.4 million over School B. There was a failure to adhere to the integrated principle of sustainability in the design.

The cistern was prevented from achieving maximum cost effectiveness because the city would not grant a well permit for refilling the storage tanks in the event there was inadequate rainfall. Had the city granted the permit, the operational costs (city water bills) would have been 0 and reduced the life cycle cost to a little over $300,000 for the 50-year service life. Even though the life cycle cost of the cistern was more than the traditional irrigation system in School B, water shortages had been on the rise for several years. If water costs increased during the 50-year life of the schools, the cistern would possibly become more cost effective, since the life cycle costs were only $21,000 apart. The windmill circulated the water in the cistern storage system and prevented the water from stagnating. A high efficiency circulating pump with a life of 20 years would cost approximately $600 and would have provided the same result. It was originally intended that the windmill would also pump the well water to refill the cistern as needed. The absence of the well prevented the windmill from reaching optimum performance. The windmill, however, provided a unique and visible teaching mechanism for students about renewable wind energy, and its life cycle cost was inexpensive over the service life of the school.

The solar H/W system was a direct heat thermal system. The water would be heated on sunny days only. The original solar system initially designed was a solar photovoltaic system on an integrated grid that produced 5 kW of electricity. The system was deleted after the bid because of its initial cost of $75,000 and the current system substituted, which was not a solar photovoltaic system, meaning it did not produce electricity from solar energy. It had no means to store electricity via a battery storage system, nor did it have the ability to borrow electricity as needed as in an integrated grid system. Because the solar H/W was not reliable on a daily basis, it was necessary to

install a gas H/W system as a backup. Even though the life cycle cost of the solar H/W was low, the addition of the gas H/W for needed redundancy, rendered the solar H/W an unnecessary expense. In examining the life cycle cost of the solar H/W, there were no maintenance, operation, or replacement costs, making the initial cost of $25,000 the life-cycle cost of the system. The original intended integrated grid, solar photovoltaic system, at an initial cost of $75,000 would have had a life-cycle cost of $75,000 over the service life of School A and would have eliminated the need for the redundant gas H/W system. The combined life cycle costs of the existing solar H/W system and the gas H/W system (which was needed for backup because of the inability of the existing system to store or borrow electricity) equaled a life-cycle cost of $485,302. The difference in life cycle cost between the intended system and the present system was $410,302, making the intended system more cost effective than the current system that was substituted after the initial bid.

The intended original mechanical system for School A was to have been a geothermal system with heat pumps. The life-cycle cost for a geothermal system similar to what would have been designed was calculated by the researcher. The initial cost was $1,054,000, a cost increase of $362,000 over the current system. The maintenance costs of the geothermal heat pumps were assumed to be equivalent to the existing heat pumps, since they were similar to the existing heat pumps at $533,603. The operations cost, based on the manufacturers calculations that the geothermal system would use approximately 25% less energy than the current system, at $3,491,968. The replacement costs were assumed to be equivalent since the geothermal heat pumps had the same expected life span as the present system at $2,956,054. The life cycle cost at NPV for the geothermal system would have been $8,035,625 or approximately $800,000 less than the

current system. It was a correct decision to delete the geothermal system since the district would have not realized a payback for the higher initial cost. These comparisons affirmed the statement made by Kowle (1979) that using life-cycle costing was a key energy saving measure that resulted in actual, not perceived, cost savings.

School A also used more gas than School B, and this should not have been the case if the solar H/W was the primary source for heating the water, because this geographical area has 234 sunny days per year. The researcher was unable to delineate why this happened since the gas H/W was not metered separately. Combining the costs of both the gas H/W and the solar H/W in School A made the School B system more cost effective.

Conclusion

The construct of sustainable renewable energy systems that has been applied in business and industry as a cost effective and efficacious option for reducing energy costs could not be successfully affirmed in this case study of educational facilities.

In support of the conclusion, the following five points are offered along with reinforcing documentation from the related literature. While the U.S. Department of Energy estimated that at least 25% or $1.5 billion could be saved annually by school by utilizing current energy saving technology found in sustainable renewable energy systems, this statement cannot be affirmed in all instances where educational facilities use sustainable renewable energy systems (Energy Smart Schools, 1997). The theory of sustainability used an integrated, holistic approach as one of its primary principles. Components should have created a synergistic affect instead of having worked against each other (American Association of School Administrators 1977; Kibert 1996; Sustainable Systems 1997; Trzyna & Osborn, 1995).

1. A primary principle of the theory of sustainability is that it is an integrated, holistic approach, and failure to adhere to this principle in the design process may result in flaws that will affect the cost effectiveness of the system. While the systems were perceived to be efficaciously equal, many did not perform to their optimum level due to what appeared to be a imperfections in their integration, affirming that sustainability was an integrated process.

The additional tonnage of heating and cooling required, combined with the use of less energy efficient equipment in School A would not appear to be an appropriate combination for using less energy. The additional tonnage was created in part by the increased number of exterior walls and larger windows in School A, primarily by the south facing light monitors for the daylighting. While daylighting in related research by Nicklas and Bailey (2001a) and Lechner (1991), the daylighting system theoretically should have reduced the heat loads created by artificial lighting and not have added to the heat loads. The reason for facing the monitors south was for the higher level of light that took place on the southern exposure. However, as stated by Lechner (1991), even though the south exposure produced the highest level of light, the light was constant from the north exposure and might have been the best exposure in hot, sunny climates in reducing the high solar heat gain and, consequently, the additional tonnage. Using the life cycle cost model developed for this case, examining the systems demonstrated that the operational efficiency within the context of the whole influenced its cost effectiveness, affirming Kowle's (1979) statement that life-cycle costing was a key energy saving measure that resulted in the actual, not perceived, cost savings.

2. The cost effectiveness and efficacy of sustainable renewable energy systems versus traditional energy systems are not just structural issues. The level of

operational efficiency within the context of the whole will influence its cost effectiveness, affirming that life-cycle costing was a key energy saving measure that resulted in the actual, not perceived, cost savings.

3. The inability to apply the sustainability theory (renewable energy systems) in educational facilities may be the result of inappropriate decisions in the design process. All decisions that are made must have a positive influence on the outcome of the objective or goal of the project. Decisions that have a negative influence are flaws and have an adverse effect on operations, not only in terms of cost but also in optimum efficacy affecting the instructional environment and performance of both teachers and students.

Sustainability was a holistic approach that considered the long-term implications and impacts of the design and construction of buildings. It was a complex construct that incorporated the interconnection of three major societal elements: economic, ecological, and social issues. Economics was concerned with the initial cost, maintenance, operations, and replacement of materials and/or systems of a building. Ecological issues involved all the resources that were required in order to facilitate construction, operation, and building consumption needs and the interaction the building had on the natural environment around it. Social issues concerned the building's interaction in the community and the health and well being of those who occupied and used it (Kibert, 1999). Social issues also involve political issues as well. The holistic nature of sustainability takes into consideration the interaction of the individual building within the community as a whole. The building influences the community and the community will exert influences upon the building, including during the design process. The political influences in this case study were the city's denial of a well permit which affected the

operational efficiency of both the cistern system and the windmill, which ultimately effected the cost effectiveness of the sustainable renewable energy systems.

4. Educational decision makers would benefit by considering the relationship between the political and economic influences in designing a school. Political influences may adversely effect the economic viability of a system in terms of the operation costs. The adverse affect on the operations cost can have an adverse affect on the instructional delivery by causing a disproportionate drain on the school district's finances.

The almost unanimous approval of the daylighting system in School A from the participants as to the mood elevating, warm atmosphere it created, reiterated the same comments made by Burrage and Bailey (1899) in their analysis of natural daylighting and affirmed Lackney's (1994) statements that students are affected by the condition of their learning environment. While student scores and absenteeism were not considered in this study, previous research had shown that daylighting did affect students in a positive manner in those areas (Nicklas and Bailey, 2001b). This factor could not be quantified in costs but may be an important consideration for the well being and performance of the students.

5. The efficacy of a system that categorically affects the condition of the learning environment and the performance of the student/teacher interaction in a positive manner may supersede its cost effectiveness. Related research in the use of the sustainable daylighting system has shown a possible positive relationship between the use of the sustainable system and the improvement in student performance. In a case where the enhanced performance of the students and the learning environment is categorically affirmed, then cost effectiveness may not be the

priority issue. The theory of sustainability incorporates both social/ethical and neoclassical (economic) perspectives; in some cases the social/ethical may take precedence.

Recommendations for Further Research

1. It is recommended that the sustainable renewable energy construct used in this study be used to compare the cost effectiveness and efficacy of renewable energy systems and traditional energy systems in other schools in different geographical and political environments.
2. The design of School A has been modified and reused within the district to build yet another school. It is recommended that the sustainable renewable energy construct developed in this study be used to compare the cost effectiveness and efficacy of the new school.
3. In related research (see Chapter 2), performance of students was improved 5% to 14% by the condition of their learning environment, specifically the use of the sustainable daylighting system. The comparison of student performance between the students in School A and School B is recommended for future study in order to document a relationship between the social/ethical construct of the theory of sustainability and the potential influence on student performance.

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BIOGRAPHICAL SKETCH

The author was born in Cleveland, Ohio, in 1950 but was raised since early childhood in Florida. A product of the 1960s, she holds a Bachelor of Fine Arts from Wesleyan College, Macon, Georgia, and was for a short time a professional artist. After several years, she gravitated back to her interest in building construction, generated from a childhood of playing with Lincoln Logs and Erector Sets, and graduated from the University of Florida with a Bachelor of Building Construction. She honed her skills in construction management throughout her 20-year career, building a wide assortment of facilities and finding that her passion was building school facilities. Seeking to do more with her skills, she returned to the University of Florida and received her Master of Building Construction. She discovered, during her time in graduate school, an equal passion for teaching. She taught as an assistant professor at Auburn University to affirm her desire to continue her career as a teacher instead of returning to industry. Once affirmed, she returned to the University of Florida a third time to complete her education with a Doctor of Philosophy degree in August 2002. The author has joined the faculty at East Carolina University as an assistant professor and will teach construction management.

The author shares her life and interests with husband, Larry, and son-in-law, Tom, who are also both construction managers, and daughter, Jennifer, who will receive her Doctor of Veterinary Medicine degree from the University of Florida College of Veterinary Medicine in 2003.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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